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THE NEW YORK ACADEMY OF SCIENCES

*SECTION OF PHYSICS AND CHEMISTRY**

THE PREPARATION OF HIGHLY CONCENTRATED NITROGEN-15 BY CHEMICAL EXCHANGE**

By W. Spindel and T. I. Taylor

Department of Chemistry, Columbia University, New York, N. Y.

Chemical exchange reactions first suggested by Urey and his co-workers[1,2] as possible methods for separating isotopes have proved to be particularly suitable for concentrating isotopes of the lighter elements. Several of the reactions that have been used and the equilibrium constants calculated from spectroscopic data are listed in TABLE 1. References are included both for the calculation of the constants and for the application of the exchange reactions to actual isotope separation processes.

In order to utilize the small differences in chemical properties for isotope separation it is necessary to multiply the single-stage separation factor. For a reaction between a liquid and a gas, this is most conveniently achieved by means of a countercurrent exchange process that is essentially similar in most respects to a continuous distillation system for separating 2 closely boiling species. FIGURE 1 is a diagrammatic representation of a distillation system arranged for the production of a component that concentrates in the liquid phase. The column shown can be any sort of fractionating column such as a bubble plate, bubble cap, or packed type, designed to achieve liquid-vapor equilibrium within a minimum height. The feed liquid enters near the upper end of the column and is enriched in the desired component as it descends. In the section of the column above the feed point the ascending vapor is stripped of the desired component. This stripping action in the section of the column above the feed point decreases the amount of feed material required for a given rate of product withdrawal. The still pot and the condenser at the ends of the column act as refluxers. The still pot converts enriched liquid to vapor and returns the vapor to the enriching section of the exchange column, while the condenser converts the depleted vapor into liquid and returns this liquid to the stripping section.

When the desired component concentrates in the vapor phase, the feed point is placed near the lower end of the column, and the names of the output streams are interchanged. In addition, the section of the column

*The Section of Geology and Mineralogy held a meeting on October 1, 1956, at which James R. Arnold of the Department of Chemistry, Princeton University, Princeton, N. J., was scheduled to deliver a paper entitled "Radioactivities Produced by Cosmic Rays." The speaker was unable to appear.

**This paper was presented at a meeting of the Section on October 2, 1956.
The work described in this paper was supported in part by a grant from the United States Atomic Energy Commission, Washington, D.C., under Contract AT (30-1)-755.

TABLE 1

CALCULATED EQUILIBRIUM EXCHANGE CONSTANTS AT 25° C.

Reaction	*Equilibrium constant*	*References*
$N^{15}H_3(gas) + N^{14}H_4^+(Aq.) \rightarrow N^{14}H_3(gas) + N^{15}H_4^+(Aq.)$	1.023	Nos. 2,3,4,5,6
$HC^{12}N(gas) + C^{13}N^-(Aq.) \rightarrow HC^{13}N(gas) + C^{12}N^-(Aq.)$	1.015	7,8
$S^{34}O_3(gas) + HS^{32}O_3^-(Aq.) \rightarrow S^{32}O_3(gas) + HS^{34}O_3^-(Aq.)$	1.014	9,10
$N^{15}O(gas) + N^{14}O_2(liq.) \rightarrow N^{14}O(gas) + N^{15}O_2(liq.)$	1.04	11,12,13,14
$N^{15}O(gas) + N^{14}O_3^-(Aq.) \rightarrow N^{14}O(gas) + N^{15}O_3^-(Aq.)$	1.09	14,15,16

between the feed point and the still pot becomes the stripping section, while the upper portion of the column is designated the enriching section.

It may be noted that if the desired component concentrates in the liquid, the system could be operated by introducing the feed stream at the very top of the column (dashed arrow), thus utilizing the entire exchange column as an enriching section. The waste refluxer would thus be eliminated, and vapor venting from the top of the column would be depleted in the desired component by, at most, only one stage of separation.

The similarity between distillation systems and chemical exchange systems is further clarified by comparing the nature of the refluxers used. For a distillation column, reflux is provided simply by a source of heat at one end and a cooling condenser at the other end. For a chemical exchange isotope separation process, reflux at the ends of the column is accomplished by chemical reactions that convert the element of interest into either a liquid or a gaseous compound at the appropriate end of the exchanger. Reflux reactions that have been proposed for the separation of carbon-13 and nitrogen-15 are listed in TABLE 2. It may be noted that, for the exchange between cyanide ion and HCN gas, the desired carbon isotope concentrates in the gas phase. The feed stream in this process is introduced near the bottom of the exchange column, and the reflux reaction taking place in the lower refluxer is the waste reflux reaction.

The over-all separation in a multistage fractionation column is given by the equation[10]

$$S = \frac{N_P}{1-N_P} \Big/ \frac{N_f}{1-N_f} = \alpha^n$$

where S is the over-all separation, N_P and N_f are the mol fractions of the desired component at the product and feed ends, respectively, α is the effective single stage enrichment factor, and n, by definition is the number of theoretical plates or separating stages.

A number of requirements for economical application of a chemical exchange reaction to the large-scale preparation of isotopes have been out-

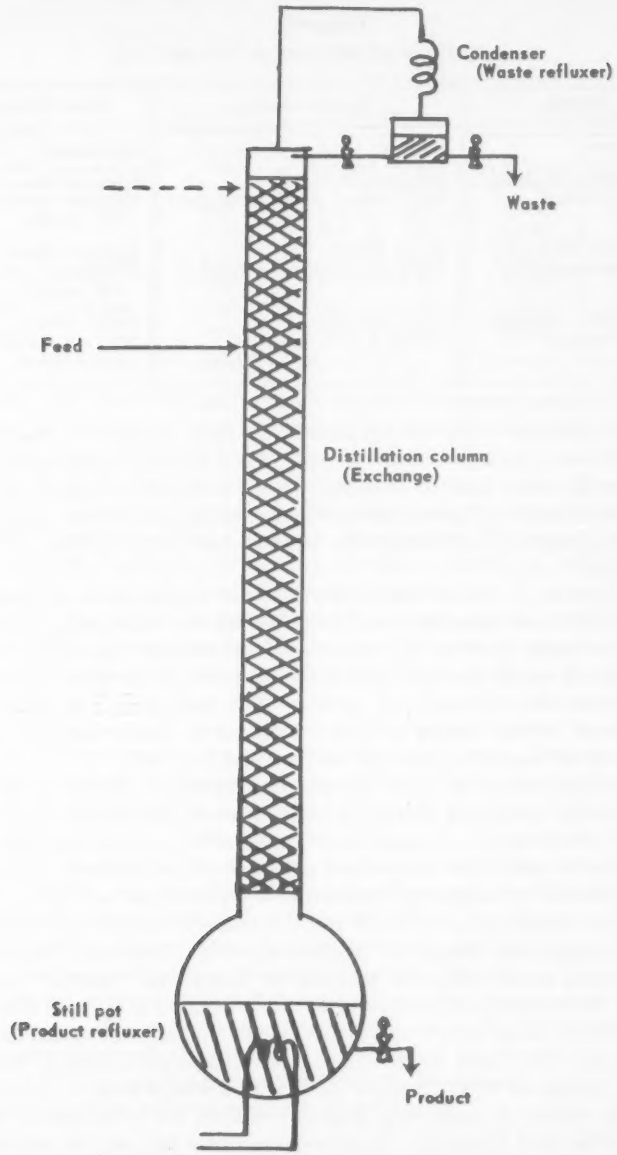

FIGURE 1. Separation system for a component that concentrates in the liquid phase.

TABLE 2
REFLUX AT ENDS OF A COLUMN

System	*Lower refluxer*	*Upper refluxer*
Distillation	Still pot	Condenser
NH_4^+ (soln) – NH_3(gas) exchange	*Product reflux:* NH_4^+ (soln) + alkali → NH_3(gas)	*Waste reflux:* NH_3(gas) + acid → NH_4^+ (soln)
CN^-(soln) – HCN(gas) exchange	*Waste reflux:* CN^- (soln) + acid → HCN(gas)	*Product reflux:* HCN(gas) + alkali → CN^-(soln)
HNO_3 (soln) – NO(gas) exchange	*Product reflux:* $2HNO_3 + 3SO_2 + 2H_2O \rightarrow 2NO + 3H_2SO_4$	*Waste reflux:* NO + air + water → HNO_3 (soln)

lined by Clewett[17]: (1) the equilibrium constant should be other than unity; (2) the exchange should be rapid; (3) a means of multiplying the single-stage effect must be available; (4) an inexpensive system for providing total reflux at the top and bottom is needed; and (5) the equipment for multiplying the single-stage effect should have a low holdup and high throughput.

For systems in which equilibrium between 2 phases is established rapidly, the most important considerations are the equilibrium constant of the exchange reaction and the means of accomplishing reflux. Other things being equal, the size of a system required to produce a quantity of material with a given mol fraction of a rare isotope is inversely proportional to the square of (α–1). That is, a system about 4 times larger will be required if α is 1.02 as compared to 1.04.

One of the major items of expense in producing isotopes by chemical exchange processes is the cost of the chemicals required. If inexpensive chemicals can be used for refluxing at the ends of the exchange column, or if marketable by-products are produced, significant economies can be effected in large-scale production of concentrated isotopes.

TABLE 3 illustrates some of the problems involved in producing a highly concentrated isotope by chemical exchange. This table lists some calculations made, using the formulas of Shacter and Garrett,[18] on the number of separating stages and reflux ratios required to produce nitrogen-15 at various assay levels by exchange reactions with separation factors of 1.02 and 1.05. Here α, the single-stage separation factor, is defined as the quotient of N^{15}/N^{14} ratios taken after a single stage of operation; N is the number of separating stages; and V/P, the reflux ratio, is the ratio of the mols of nitrogen of natural abundance fed into the system to the mols of enriched nitrogen produced. The values of 1.5 N (min.) and 1.4 (V/P) (min.) were arbitrarily chosen as reasonable for a cascade actually producing nitrogen-15. For example, if we consider an exchange

TABLE 3

NUMBER OF STAGES AND REFLUX RATIOS

Per cent N^{15} required	Over-all separation	Effective single-stage factor (α)	Stages		Reflux ratio	
			1.5 N(min.)	N(min.)	1.4 V/P(min.)	V/P(min.)
60%	404	1.02	455	303	11,326	8,090
		1.05	185	123	4,530	3,236
95%	5,390	1.02	647	431	17,969	12,835
		1.05	270	180	7,187	5,134
99.9%	269,000	1.02	947	631	18,900	13,500
		1.05	384	256	7,560	5,400

between nitric acid and nitric oxide where α is approximately 1.05, the production of 99.9 per cent nitrogen-15 requires 384 separating stages. For every gram atom of 99.9 per cent nitrogen-15 produced, it is necessary to convert about 7500 gm. mols of nitric acid to nitric oxide. To produce the same quantity of isotopes by the ammonium ion-ammonia exchange reaction where α is about 1.02 would require about 947 stages; for each gram atom of 99.9 per cent nitrogen-15 almost 19,000 gm. mols of ammonium ion would have to be converted to ammonia.

The interest in large-scale nitrogen-15 separation lies in its possible applications in the nuclear field because of its low neutron capture cross section and the high solubility of most of its nitrates. If problems associated with corrosion and radiation decomposition of nitrates can be solved, nitrogen-15 may find use in the thorium blanket of a homogeneous breeder reactor for producing electrical power. Thorium nitrate has the required solubility, but the thermal neutron absorption cross section of nitrogen-14 is 1.9 barns, while that of nitrogen-15 is 2.4×10^{-5} barns. Ninety-five per cent nitrogen-15 would have a cross section of 0.11 barns and would be suitable. In a recent report, Hayford, Johnson, Levin, Shacter, and von Halle[19] considered several possible processes for the large-scale production of nitrogen-15 for homogeneous nuclear reactors and concluded that chemical exchange was the most feasible method for the economical production of isotopic nitrogen.

In several communications[14,16] we have reported experiments on the concentration of isotopic nitrogen by a chemical exchange process that offers significant advantages over the ammonium ion-ammonia exchange system.[2-6,19] The exchange reaction tends to concentrate the isotope in the solution phase and may nominally be written as

$$HN^{14}O_3 + N^{15}O \rightleftarrows HN^{15}O_3 + N^{14}O$$

Actually, exchange between the liquid and gas phases is most effective for isotope separation at a nitric-acid concentration of about 10 molar,

when the column is operated at room temperature and atmospheric pressure. Under these conditions the solution phase contains, in addition to nitric acid and water, NO, NO_2, N_2O_3 and HNO_2, while the gas phase in equilibrium contains NO, NO_2 and N_2O_4 and H_2O vapor.[20] The effective α for the exchange is actually 1.05 in the operating system as compared to the theoretical value of 1.09 calculated for exchange between pure nitric oxide and nitrate ion, but this value of α compares favorably with α for the ammonium-ammonia exchange.

The equations for the reflux reactions illustrate some of the novel economies possible in this process. At the product end of the exchange column, SO_2 reacts with HNO_3 to form NO (with some NO_2) and H_2SO_4 according to the equations

$$2\,HNO_3 + 3\,SO_2 + 2\,H_2O \rightarrow 3\,H_2SO_4 + 2\,NO$$

$$2\,HNO_3 + SO_2 \rightarrow H_2SO_4 + 2\,NO_2$$

The reaction is rapid and complete in the type of reflux reactor used. Less than 5 parts per million of the HNO_3 flow in the exchange column have been found to escape with the sulfuric acid from the bottom of the reactor.

For each mol of sulfur dioxide used, one mol of sulfuric acid is obtained at a concentration of approximately 10 mols per liter. Thus the use of relatively inexpensive commercial grade SO_2 and the production of a chemical that can be sold as a by-product contribute to lowering the cost of this reflux operation.

The reflux reactor at the waste end of the column converts the NO and NO_2 to nitric acid by reaction with air and water

$$4\,NO + 3\,O_2 + 2\,H_2O \rightarrow 4\,HNO_3$$

The low cost of air and water makes this part of the process economical. The nitric acid can be returned for commercial use, since removal of a fraction of its nitrogen isotope does not measurably affect its chemical properties.

The raw materials for the process are nitric acid, sulfur dioxide, air, and water. In effect, one borrows the nitric acid to remove some of its nitrogen isotope and returns sulfuric acid for the sulfur dioxide used.

A laboratory-scale exchange system used to study the effect of nitric acid concentration, pressure, and liquid flow rate on the isotope separation is shown in FIGURE 2. Nitric acid entering the product refluxer reacts with SO_2 in a zone about 10 cm. long in the packed refluxer. The reaction zone is easily detected by the color of the NO_2 or by a rather marked rise in temperature caused by the exothermic reaction. A photometer cell is used to control automatically the position of the reaction zone by opening a by-pass solenoid valve in the SO_2 line whenever the color of NO_2 in the cell becomes too intense. A small amount of water

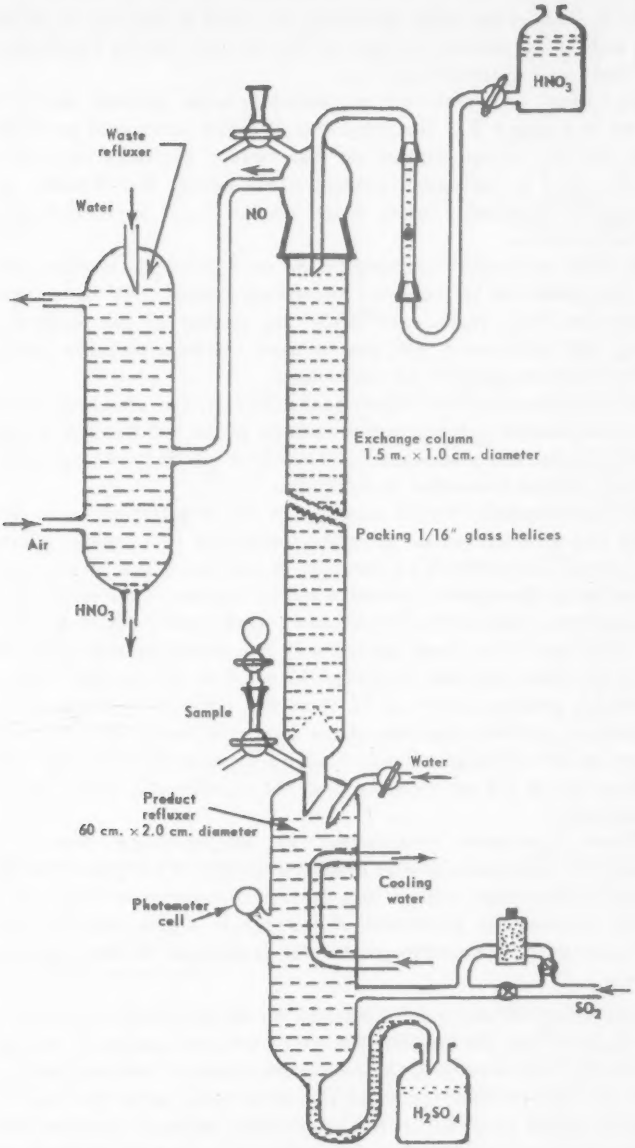

FIGURE 2. Exchange system for separation of nitrogen isotopes by exchange of nitric oxide with nitric acid.

(0.05 to 0.10 of the nitric acid flow) is added at the top of the refluxer to maintain the partial pressure of NO_2 at about that in equilibrium with the nitric acid in the column.

As a result of experiments on laboratory-scale systems such as those shown in FIGURE 2 it was found that 10 molar nitric acid gave the optimum over-all isotope separation. The isotope exchange rate was sufficiently rapid at nitric acid concentrations greater than 8 molar, as evidenced by reasonably short stage heights found in various types of packed columns.

At nitric acid concentrations as low as 2 molar the reaction rate was low, as evidenced by the small separation obtained. At higher acid concentrations NO_2, N_2O_3, and HNO_2 are present in the solution phase along with nitric acid, and one or more of these probably acts as an intermediate to speed up the exchange.

At acid concentrations higher than 10 molar, the increased concentration of dissolved species in the solution phase and the partial pressure of NO_2 in the gas phase lower the value of α (effective) and reduce the over-all isotope separation in a column.

An approximately twofold increase in the operating pressure does not lower the over-all isotope separation achieved in a column. Curves for the over-all separation as a function of time are given in FIGURE 3 for operation at atmospheric pressure and in FIGURE 4 for operation at 1.9 atmospheres. Both sets of experiments were carried out in a column 1.0 cm. I. D. and 1.5 m. long, packed with one sixteenth-inch glass helices. When the flow rate was increased from 1.6 to 3.2 cc./cm.^{2}/min. at atmospheric pressure (FIGURE 3), there was a marked decrease in over-all separation, probably because of the increased linear velocity of the gas phase in the exchange column. FIGURE 4 shows that the same increase in flow rate at 1.9 atmospheres does not significantly affect the over-all separation.

These experiments demonstrate that the exchange columns can be operated at pressures greater than atmospheric, with a corresponding increase in flow rate, without loss in over-all separation. This, of course, would increase the production of isotopes in a given column and could be important so far as the commercial application of the method is concerned.

The effect of increase in pressure in the NO-HNO_3 exchange system is opposite that for the NH_3-NH_4NO_3 exchange system.[4,5] In the latter system, it was necessary to operate the column at reduced pressure ($\sim$ 8 cm.) in order to lower the solubility of the NH_3 gas in the liquid phase. The increased solubility of NO at increased pressure does not adversely affect the over-all separation for the NO-HNO_3 system, probably because the NO reacts with the nitric acid to form more N_2O_3 and HNO_2 in the liquid phase. These serve as intermediates in the exchange.

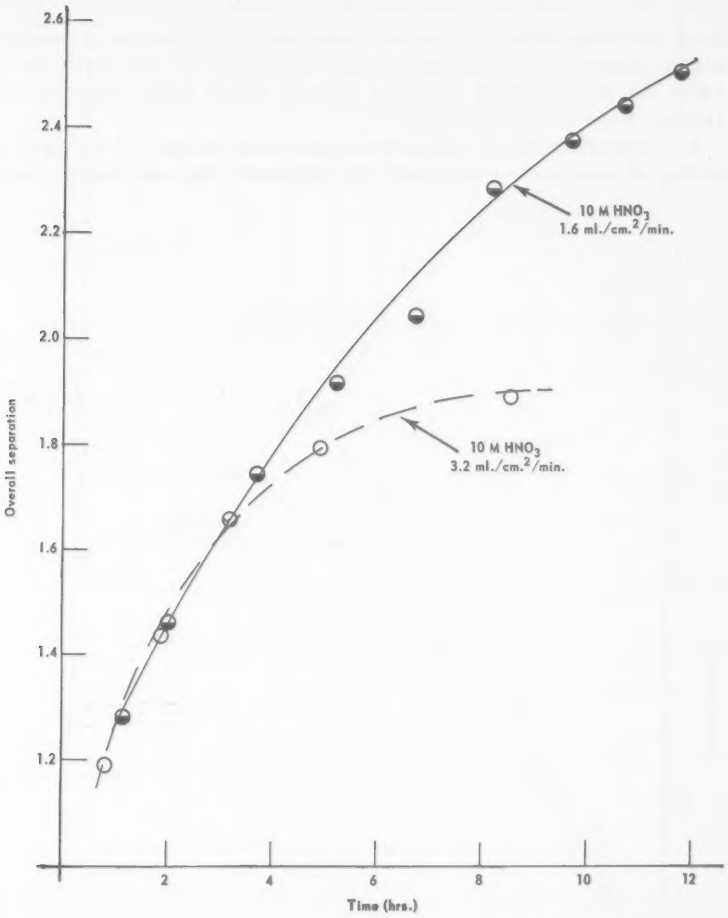

FIGURE 3. Effect of flow rate on over-all separation at 1.0 atmosphere pressure for 10 molar nitric acid.

It appeared desirable to set up an apparatus to produce very highly concentrated nitrogen-15 by the nitric acid-nitric oxide exchange. First, it was felt that, by actually operating a system producing laboratory quantities of nitrogen-15, one could directly demonstrate that losses of enriched nitrogen from the product refluxer, or the formation of non-exchanging compounds of nitrogen by side reactions in the refluxer, were not of sufficient magnitude to prevent the production of enriched nitrogen by the process. Second, it was felt that laboratory quantities of very highly concentrated nitrogen-15 would be valuable in scientific investiga-

tions involving either the nuclear properties of the isotope or spectroscopic properties of compounds containing nitrogen-15 and would be of value for tracer studies involving nitrogen where highly concentrated isotopic material was necessary.

A "tapered" cascade system was constructed because of the smaller holdup of enriched material and the decreased time required to reach

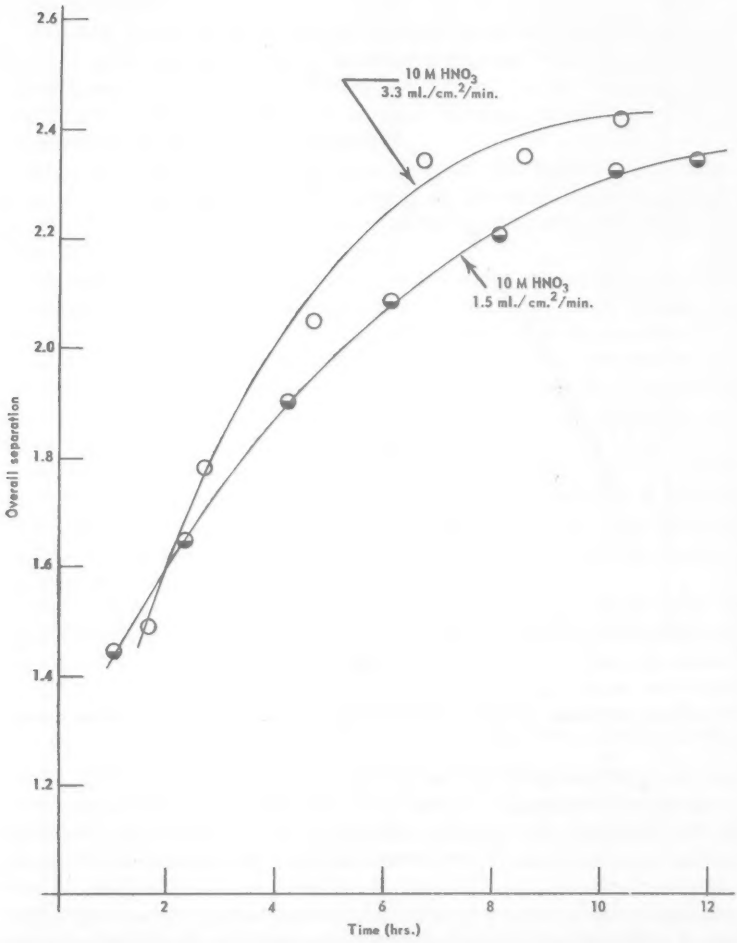

FIGURE 4. Effect of flow rate on over-all separation at 1.9 atmospheres pressure for 10 molar nitric acid.

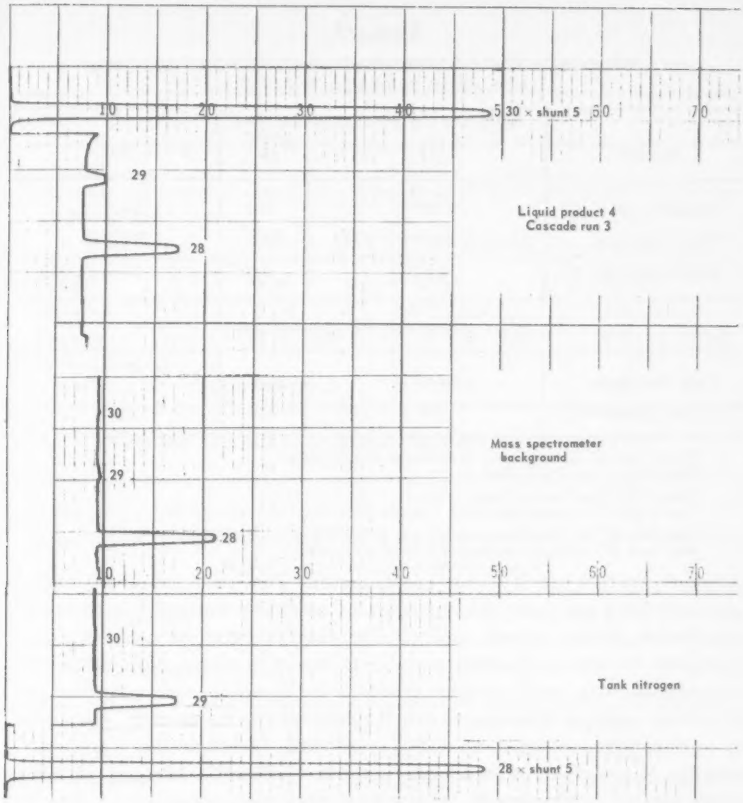

FIGURE 5. Mass spectrum of 99.9 per cent nitrogen-15.

steady state separation.[10,21] A 2-stage unit was chosen in order to keep the number of product refluxers, interstage pumps, and lines at a minimum. The main function of the cascade was to demonstrate the feasibility of the process rather than to produce quantities of enriched material.

The cascade system constructed and some of the results obtained have been described previously.[16] The cascade was operated for 14 days without withdrawal of enriched material from the product end except for 30 cc. atmospheres per day of nitric oxide for isotopic analysis. After 14 days, the cascade had reached a steady state separation at 99 + per cent N^{15}. Operation was continued for another 11 days. During this time about 6 gm. of nitrogen containing 99 + per cent N^{15} were withdrawn either as nitric acid, or as nitric oxide containing some nitrogen dioxide.

Samples were reduced to elementary nitrogen before analysis for

TABLE 4

PERCENTAGE OF NITROGEN-15 IN ENRICHED SAMPLE DATA FROM SPECTRA IN FIGURE 5

Sample	*Mass 28*	*29*	*30*
Background	30*	1.0	<0.5
Tank nitrogen	121.5 × 23.0** = 2790	20.5	<0.5
Liquid product 4	24	6.0	122 × 23.0 = 2810
After subtracting background peaks			
Tank nitrogen	2760	19.5	
Liquid product 4	<0	5.0	2810

*Peak heights all measured in arbitrary height units.
**Sensitivity factor for shunt 5.

Ratio 28/29 in tank nitrogen = 141.5.
Ratio 30/29 in liquid product 4 = 562.

Per cent N^{14} in liquid product 4 = 141.5/562 × 0.365 = 0.09 per cent N^{14}.
Per cent N^{15} in liquid product 4 = 99.91 per cent N^{15}.

isotopic content on a mass spectrometer. The most enriched sample analyzed 99.9 per cent N^{15}. In order to establish the exact nitrogen-15 abundance of this sample and of other highly enriched samples, it is desirable to use a standard sample of known isotopic composition for comparison. The most obvious standard for comparison is nitrogen gas of natural isotopic abundance. Nier[22] measured the nitrogen-15 abundance in atmospheric nitrogen as 0.365 per cent. Although the "unknown" sample of enriched nitrogen gas and the "natural" nitrogen standard differ greatly in nitrogen-15 composition, they are comparable in that the standard contains a small amount of N^{15} in a large quantity of N^{14}, while the unknown contains a small amount of N^{14} in a large quantity of N^{15}. A comparison of mass spectra for the highly enriched and natural-abundance nitrogen permits a precise and accurate determination of the N^{15} abundance.

FIGURE 5 shows a recorded mass spectrum of a highly enriched nitrogen sample together with a spectrum of tank nitrogen and a spectrum showing the background peaks in the instrument, all taken over the mass range of 28 to 30. It may be noted that, while the mass 30 peak of the enriched sample is comparable in magnitude to the mass 28 peak in tank nitrogen, the mass 29 peak in the enriched sample is only about one quarter of the 29 peak in the standard. TABLE 4 indicates a sample calculation of the percentage of nitrogen-15 in an enriched sample. One can readily determine the concentration of nitrogen-15 as 99.9 ± 0.01 or 0.02 per cent, even though the standard sample contains only 0.365 per cent nitrogen-15.

TABLE 5

CASCADE PARAMETERS FOR NITROGEN-15 CONCENTRATION

Ammonia-ammonium ion exchange[5]

Cascade	*Three stage*		
Exchange section	1	2	3
Length	24 m.	12 m.	7.5 m.
Diameter	7 cm.	2.2 cm.	1.0 cm.
Feed rate	70 cc./min.*	7.5 cc./min.*	0.85 cc./min.*
N^{15} concentration in feed	0.365%	2.61%	18.9%

Production rate and concentration: 0.63 gm./day N^{15} at 72.8 %

*Sixty per cent by weight of ammonium nitrate solution.

Nitric oxide – nitric acid exchange

Cascade	*Two stage*	
Exchange section	1	2
Length	5.2 m.	5.5 m.
Diameter	2.5 cm.	0.9 cm.
Feed rate	15 cc./min.**	0.75 cc./min.**
N^{15} concentration in feed	0.365%	~5.0%

Production rate and concentration: 0.5 gm./day N^{15} at 99+ %

**Ten molar nitric acid.

It is interesting to compare the cascade system used by Thode and Urey[5] to concentrate nitrogen-15 by exchange between ammonia and ammonium ion with the system used in the present research. A brief tabulary summary is presented in TABLE 5.

Acknowledgment

The authors gratefully acknowledge the assistance of various members of the laboratory, particularly of Karl Schumann, who constructed the glass columns and refluxers; of Rudolph Froeder, Gleb Gashurov, Henry Kramer, and Ronald Kent, who assisted in the construction and operation

of the cascade; of Vincent Saltamach, who assisted in the analysis of the nitrogen; and of Lois Nash Kauder, who determined the single-stage-enrichment factor for the exchange reaction.

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SECTION OF BIOLOGY

I. EFFECTS OF VARIOUS FACTORS ON THE SYNTHESIS OF ASCORBIC ACID BY THE AMERICAN COCKROACH *PERIPLANETA AMERICANA* L.*

By Gerald Rousell

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Ascorbic acid has been reported in the tissues of a number of insects. However, very few studies have been carried out concerning its synthesis by insects. Wollman, Giroud, and Ratsimamanga (1937) have presented indirect evidence that the cockroach *Blatella germanica* is able to bring about this synthesis. They raised cockroaches under aseptic conditions for 15 years on a vitamin C-free diet and found that they contained as much ascorbic acid as specimens that were fed a diet containing the vitamin. Gamo and Seki (1954) reported that homogenates of pupal fat bodies of the silkworm *Bombyx mori* were able to convert mannose into vitamin C. The purpose of the present work was to determine the optimal conditions for the synthesis of ascorbic acid by homogenates of the cockroach *Periplaneta americana*. The effects of the nature of the substrate, concentration of substrate, concentration of homogenate, pH, length of incubation period, temperature of incubation, and addition of manganese ion to the solution were determined. Experiments were also carried out using homogenates of only fat bodies.

In these investigations the homogenates were incubated with the substrate under the desired conditions, and the ascorbic acid content was measured by the method of Roe and Keuther (1943), as modified by Schaffert and Kingsley (1955). In the spectrophotometer readings 2 blank tubes were used: one containing no homogenate to set the instrument, and another containing homogenate that was not incubated and which indicated the original amount of ascorbic acid in the tissue.

The results show that the monosaccharides – mannose, glucose, fructose, galactose, and xylose – and also the disaccharide sucrose were utilized as precursors in the synthesis of ascorbic acid. Mannose produced the greatest amount, 18.6 μg./gm. and xylose the least, 7.2 μg./gm. A substrate concentration of 5×10^{-3} M was optimal with a synthesis of 18.4 μg./gm. A 3-hour incubation period was found to be optimal, an average rate of 6 μg./gm./hr. being synthesized. A slightly acid medium (pH 6.8) proved to be the most favorable for ascorbic acid synthesis. Most rapid synthesis occurred in the temperature range between 25° and 30° C. The addition of manganese ion to the incubation mixture did not result in an increased synthesis. Twenty per cent homogenate

*This article, illustrated with lantern slides, was the first of two papers presented at a meeting of the section on October 8, 1956.

concentration proved to be the most effective, producing 19.2 μg./gm. Homogenates of fat bodies produced greater amounts of ascorbic acid (26.0 μg./gm.) than homogenates of whole insects (18.6 μg./gm.).

The values reported for fat body homogenates are somewhat lower than those reported by Gamo and Seki (1954) for homogenates of fat bodies of prepupa, 1-day and 2-day pupa of *Bombyx mori*. The temperature of 25° C., optimal in these tests, agrees with the results reported by Gamo and Seki (1954).

These results do not exclude the possible role of microorganisms present in the mycetocytes of the fat bodies (Gier, 1936).

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II. THE CHROMATOGRAPHIC SEPARATION OF AMINO ACIDS FROM INSECT BLOOD*

By Donald S. Po Chedley

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Paper chromatography is one of the most versatile of modern analytical methods for separating mixtures of organic and inorganic compounds. Since only a few micrograms of material are required for analysis, this method has contributed to the rapid increase of data concerning free amino acids of insect haemolymph. Publications of Auclair (1953) and Auclair and Maltais (1954) provide useful summaries of its entomological applications. This report deals with specific details of the chromatographic method employed for the identification of the free amino acids in the blood of larvae of the Oriental beetle, *Anomala orientalis*.

Amino-acid separation was accomplished by the descending method of Consden, Gordon, and Martin (1944) and the ascending technique of Williams and Kirby (1949). The appraisal of flow and the partitioning patterns indicate that the main mass of the partitionable substance preceded its tail (comet formation) during descent and followed it during ascent. Since tail formation sometimes obscures other closely partitioned components, the use of both procedures aided identification of the separated compounds.

Analyses of a range of blood volumes, deproteinized by the method of Pratt (1950), indicated that amounts of from 1 to 5 μl. were most suitable for study. Too large a volume caused the spots to overlap, while smaller quantities yielded partition products below the indicator reagent's range of sensitivity (Pratt and Auclair 1948). The diameter of the sample at the origin was restricted to approximately 2 mm. Concentrated material may be applied over a larger area than a dilute sample, as the latter assumes a peripheral distribution at the origin which is responsible for irregularly shaped spots.

Standard solutions containing 0.025 mg. per ml. amino nitrogen of each amino acid were run in each of the solvents used in this study. Data were thus obtained concerning the homogeneity of the compounds, Rf values, partitioning characteristics, and solvent reactions. A mixture of 18 amino acids, used for 2-dimensional surveys, revealed relationships between the chemical structure and the partition patterns (Polson 1949). Specific identification of the blood components was obtained by comparisons with known mixtures of the reference amino compounds (Auclair

*This paper, illustrated with lantern slides, was the second of two papers presented at a meeting of the Section of Biology, October 8, 1956. It is part of a doctoral dissertation submitted to Fordham University, New York, N. Y., in February 1956. The author gratefully acknowledges the guidance and assistance given by Daniel Ludwig, Fordham University. Helpful suggestions were made by H. R. Roberts, National Dairy Research Laboratories, Long Island, N. Y., and by J. D. Hilchey, Quartermaster Research and Development Center, Natick, Mass.

and Dubreuil 1952) and the one-dimensional replication method of McFarren (1951).

Whatman No. 1 filter paper, used throughout this study, gave consistently good results when it was prewashed with the solvent to condition it physically and chemically for the run (Schute 1952, Miller 1956). The washed papers were ruled with 2 parallel lines 1 cm. apart and about 2 to 5 cm. from the edge of the sheet. The line closer to the edge represented the submersion limit of the paper and insured a constant origin-solvent distance for all chromatograms. Variations of this distance were associated with fluctuating Rf values of the partitioned compounds. In this study, papers 32 cm. in length, run from 15 to 18 hours at 25° C., satisfied partitioning requirements. The results of different chromatograms are more easily compared when the papers are of standard length. Prior to the run, the papers with the samples applied were equilibrated with the tank atmosphere for at least 2 hours. It was necessary to line the large tanks with filter paper saturated with solvent to avoid atmospheric stratification, which impairs the efficiency of the run, especially during the ascending flow.

The temperature must be held constant while the run is in progress since variations will induce water-logging of the paper, partitioning difficulties, and altering of the atmosphere and the solvent. While chromatograms may be obtained through a wide range of temperatures, it is advisable, for purposes of repetition, to make all runs at the same temperature.

Papers were thoroughly freed of solvent by air drying before applying the ninhydrin reagent, particularly when phenol or cresol solvents had been used. Since the reactivity of ninhydrin varies from one lot to another, it was necessary to test the effectiveness of each new batch. Spraying or dipping with the indicator caused the formation of colored spots, indicating the presence of amino compounds. The ninhydrin reaction detects not only α-amino acids, but also other types of amino compounds. β-alanine and taurine were located after copper complexes had been formed with the α-compounds (Crumpler and Dent 1949). Identification of the individual amino acids was made by color, by Rf value (which is constant for a substance under a given set of conditions), by comparison with standard runs, and by chromatogram maps.

The procedure was made quantitative by the methods of McFarren and Mills (1952) and Block, Durrum and Zweig (1955). Quantitative readings augment the validity of qualitative results. Transmission values for an amino acid that partitioned separately in one solvent but overlapped with another compound in a different solvent were variable. These differences were resolved by tentatively listing the possible amino acids of close Rf values, making runs in several different solvents, until transmission values were constant.

TABLE 1 contains the solvents, the pH and Rf values, the partitioned compounds, and the references that were found to be most suitable. Solvents were tested periodically by noting their partitioning effect upon the amino-acid standards. Phenol, cresol, 2,6-lutidine, and collidine are quite stable. Partitioning irregularities due to volatility and esterification of alcohol solvents may be avoided by preparing this type of solvent prior to the run.

TABLE 1

SOLVENTS, RF VALUES, AND AMINO COMPOUNDS OF BLOOD OF THE ORIENTAL BEETLE LARVA

Compound	*Rf values and solvents**												
	A	B	C	D	E	F	G	H	I	J	K	L	M
α-Alanine			48	14	16			60	28	46	37	45	
β-Alanine								60				48	
α-Amino-*n*-butyric acid							31		34		43		
Arginine				19						26			
Asparagine		28						38			17	18	
Aspartic acid		10	10					19			21		
Cystine	13												
Glutamic acid		15	17					31			25		
Glutamine		48										27	
Glycine		23	38									37	
Histidine				37	35					23			
Isoleucine										83			80
Leucine										86			85
Lysine					40					18			
Methionine				55	52								
Ornithine		69										22	
Phenylalanine				70			48			76			
Proline				65		29							
Serine			27					36					
Taurine							40		40	29		41	
Threonine		32	41										
Tryptophane						68							
Tyrosine	56												
Valine				42	46	38							

Solvent	*pH values*	
A – phenol	pH 2.0	McFarren (1951)
B – phenol	pH 7.5	
C – phenol	pH 12.0	
D – meta-cresol	pH 8.4	
E – meta-cresol	pH 9.7	
F – 2,6-lutidine	pH 9.0	
G – collidine	pH 12.0	
H – phenol		Block, Durrum, and Zweig (1955)
I – 2,6-lutidine-collodine		Block, Durrum, and Zweig (1955)
J – *n*-butanol-acetic acid		Woiwod (1949)
K – *n*-butanol-formic acid		Wiggins and Williams (1952)
L – *t*-butanol-formic acid		Underwood and Rockland (1954)
M – collidine		Taurog, Tong, and Chaikoff (1950)

*The amino compounds used for reference and the organic solvents were obtained from the Eastman Organic Chemicals Department, Rochester, N. Y.

The 21 free amino acids and 3 derivatives identified in the blood of Oriental beetle larvae by this method are: α-alanine, β-alanine, α-amino-*n*-butyric acid, arginine, asparagine, aspartic acid, cystine, glutamic acid, glutamine, glycine, histidine, isoleucine, leucine, lysine, methionine, ornithine, phenylalanine, proline, serine, taurine, threonine, tryptophane, tyrosine, and valine.

Paper chromatography is one of the most efficient of available methods for the analysis of insect blood. This technique has the advantages of simplicity, ease of operation, rapid interpretation, and high sensitivity. Meticulous care in the control of temperature, equilibration, spot diameter of the sample, indicator reagent, solvent-origin distance, and partitioning potential of the solvents is necessary if consistent results are to be attained.

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*SECTION OF MATHEMATICS AND ENGINEERING**

THE APPLICATION OF THE STRING-NET ANALOG IN PROBLEMS ON THE TORSION OF SHAFTS WITH KEYWAYS**

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INTRODUCTION

Saint-Venant [1-6] derived the partial differential equation and the boundary condition (EQUATIONS 3 and 5), the solution of which will give the stress distribution over the right section of any prismatic shaft. He solved the problem for a few sections only: the ellipse, the equilateral triangle, the square, and the rectangle, all cases in which the mathematical method is suitable. Shafts with keyways require resort to some analog, such as the soap film suggested by Karl von Prandtl, the string net, calculating machines that can solve partial differential equations with boundary conditions, and the powerful method of relaxation developed by Southwell. [7-11]

The equation of Saint-Venant and the boundary condition can take different forms. It is necessary in this introduction to develop briefly these 3 forms in order to clarify the suitability of the individual forms for the methods of numerical solution listed above.

THE 3 FORMS OF PARTIAL DIFFERENTIAL EQUATIONS AND THE CORRESPONDING BOUNDARY CONDITION THAT GOVERNS THE PROBLEM OF TORSION

The Theory of Saint-Venant: Form 1

The z axis will be taken parallel to the surface elements of the prismatic shaft and passed through the center of inertia of any right section of the shaft. The x and the y axes will lie in the plane of the section, in any orientation, and pass through the center of inertia of the section.

Saint-Venant assumed the deformations at any point of the section to be

$$u = -\alpha xyz, \qquad v = \alpha xz, \qquad w = \alpha \phi \tag{1}$$

where α is the angle of twist per unit length of shaft and the right section deforms, under the action of the torque, to the surface $w = \alpha \phi$.

Under the imposed deformations, 2 stress components remain in the

*The Section of Psychology held a meeting on October 15, 1956, at which a paper "Relations Between Auditory Psychophysics and Auditory Electrophysiology" was presented by Walter Rosenblith of the Massachusetts Institute of Technology, Cambridge, Mass. This paper will be published in the December issue of the TRANSACTIONS.

**This paper, illustrated with lantern slides, was presented at a meeting of the Section on October 19, 1956.

general equations of the theory of elasticity, the x and the y components of shear stress

$$\tau_{zx} = \mu\,\alpha\left(\frac{\partial\phi}{\partial x} - y\right), \qquad \tau_{yz} = \mu\,\alpha\left(\frac{\partial\phi}{\partial y} + x\right) \tag{2}$$

where μ is the modulus of elasticity for shear, and ϕ must satisfy the equation of Laplace:

$$\frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} = 0 \tag{3}$$

There is a boundary condition to be satisfied: the prismatic surface of the shaft must be free of stress. The resultant of the stress components (EQUATION 3), must be tangent to the shaft surface. This condition is expressed by EQUATION 4, FIGURE 1,

$$\tau_{zx}\cos(x,n) + \tau_{yz}\cos(y,n) = 0 \tag{4}$$

where (x,n) and (y,n) are the angles between the normal, n, to the boundary measured outward from the boundary and the x and the y axes respectively.

The boundary condition can be given a more convenient form shown in EQUATION 5. Using EQUATIONS 2 and 4 and the expansion of $\partial\phi/\partial n$, the boundary condition becomes

$$\frac{\partial\phi}{\partial\eta} = \frac{\partial\phi}{\partial x}\cos(x,n) + \frac{\partial\phi}{\partial y}\cos(y,n) = y\cos(x,n) - x\cos(y,n) \tag{5}$$

The boundary is unknown until ϕ is found. While the condition shown in EQUATION 5 can be applied in the use of the string net, the remaining 2 forms are much easier to use.

Form 2 of the Equation and the Boundary Condition that Governs the Torsion Problem

The function $\phi\,(x,y)$ (EQUATION 3), which satisfies the equation of Laplace has a conjugate form $\psi\,(x,y)$, for which the relations are

$$\frac{\partial\phi}{\partial x} = \frac{\partial\psi}{\partial y}, \quad \frac{\partial\phi}{\partial y} = -\frac{\partial\psi}{\partial x}, \text{ and } \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} = 0 \tag{6, 7}$$

The boundary condition for ψ takes on a new form. From EQUATION 5 and $\frac{\partial\phi}{\partial n} = \frac{\partial\psi}{\partial s}$, $\cos(x,n) = \frac{dy}{ds}$, $\cos(y,n) = \frac{dx}{ds}$, and (FIGURE 1)

$$\frac{\partial\psi}{\partial s} = y\frac{dy}{ds} + x\frac{dx}{ds} \text{ and } \psi = \frac{1}{2}(x^2 + y^2) + C \tag{8, 9}$$

The right section (that is, of the boundary only) of the shaft is distorted to assume the form shown in EQUATION 9, while EQUATION 7 governs within and up to the boundary. This boundary can be built to any scale,

over which a string net can be strung to satisfy EQUATION 7. The constant C can be taken as zero for solid shafts.

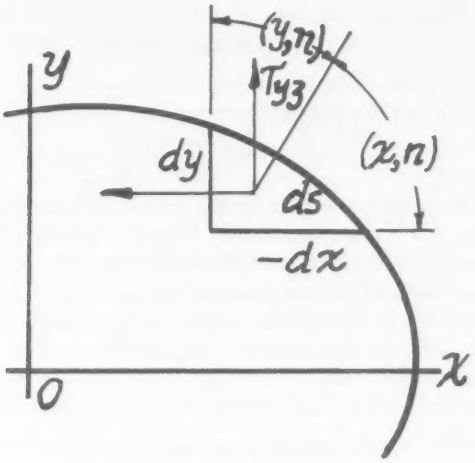

FIGURE 1.

Form 3 of the Equation and the Boundary Condition that Governs the Torsion Problem

Prandtl suggested the function Ψ (EQUATION 10) over the boundary,[6]

$$\Psi = \psi - \tfrac{1}{2}(x^2 + y^2) \tag{10}$$

The differential equation, EQUATION 11, now takes on the form of a special case of the equation of Siméon D. Poisson,

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + 2 = 0 \tag{11}$$

The boundary condition for the ψ function is a constant C; a plane right section which can be taken through the origin for solid shafts.

EQUATIONS 2 take on the simpler forms of EQUATIONS 12

$$\tau_{zx} = \mu\alpha \frac{\partial \Psi}{\partial x}, \quad \tau_{yz} = -\mu\alpha \frac{\partial \Psi}{\partial y} \tag{12}$$

The resultant shear stress at any point x, y is

$$R = \mu\alpha G \tag{13}$$

where G is the gradient of the surface ψ at that point, and

$$G = \left[\left(\frac{\partial \Psi^2}{\partial x}\right) + \left(\frac{\partial \psi^2}{\partial y}\right)\right]^{1/2} \tag{14}$$

which has a scalar value independent of the algebraic signs of the derivatives.

The reaction of the stresses (EQUATIONS 12) form a couple, T (EQUATION 15).

$$T = 2\mu\alpha \iint \Psi \, dxdy = 2\mu\alpha C \tag{15}$$

where C is the volume under the surface ψ to $\psi = 0$.

In terms of EQUATION 2, the torque reaction is

$$T = \mu\alpha I_\rho + \mu\alpha \iint \left(x\frac{\partial \phi}{\partial y} - y\frac{\partial \phi}{\partial x} \right) dxdy \tag{16}$$

where I_ρ is the polar moment of inertia of the section. For $\phi = 0$, the torque reduces to $T = \mu\alpha I_\rho$. EQUATION 5 for $\phi = 0$ defines the section as that of a circle, the only section for which $T = \mu\alpha I_\rho$. For the circular shaft the right sections remain plane on the twisting of the shaft under torsion. The shaft with noncircular section will give more torque reaction than the calculation by polar moment alone indicates. The value of μ is obtainable from round shafts, not readily from a square shaft. For solid shafts the circular form of shaft is more efficient in the use of metal.

The Form of ϕ for Square Shafts

FIGURE 2 shows a picture of the approximate form of the surface $w = \alpha\phi$, for the twist $\alpha = 1$. From EQUATION 5, $\frac{\partial \phi}{\partial n} = -\frac{\partial \phi}{\partial x} = a$, at point A,

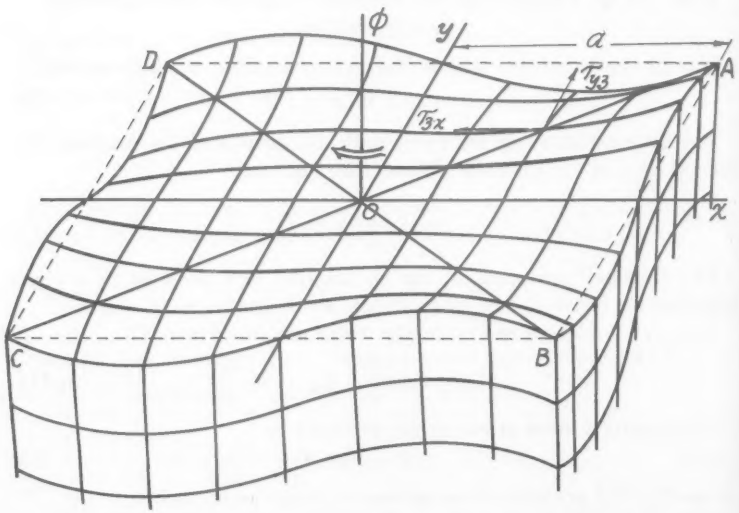

FIGURE 2. Surface $w = \alpha\phi$ of a right section of a square shaft, twisted left hand.

and changes sign at B, and the slope is equal to y from $y = a$ to $y = 0$, with corresponding values on the rest of the border. The axes remain in the plane and, for the square section, the diagonals remain in the plane. The surface ϕ for any section can be obtained from the ψ net by using the relations shown in EQUATIONS 6.

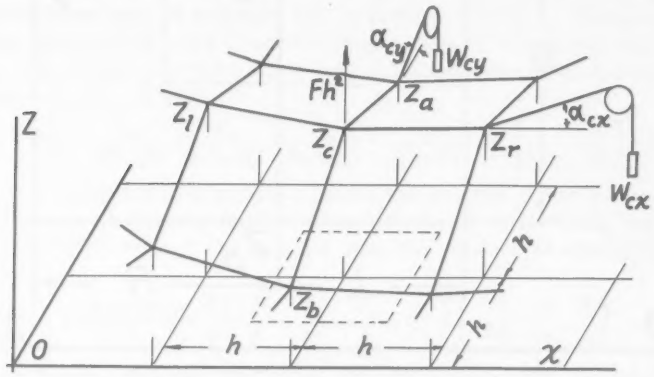

FIGURE 3. The string net.

THE STRING NET ANALOG

The String Net; the Loaded Poisson Net

FIGURE 3 shows a series of y strings parallel to the Zy plane, with equal spacing, h, crossed by a series of x strings parallel to the Zx plane and with the same spacing, h. Each string is tied at one end to the boundary; at the other end each string passes over a low-friction pulley and is attached to a weight, or to a spring. The strings project orthogonally to a square plot, h by h, on the xy plane. A loop of thread, about three-fourths in. diameter is tied by a slip knot over the crossing strings to form a node. The 2 strings can each be made to slip in the knot and can be adjusted to project as required.

A force function, *$F(x,y)$, in pounds per unit of projected area on the xy plane,* times h^2, acts at the nodes, in the direction of the Z axis, and positive in the upward direction. Actually, weights are very convenient to use; the surface is reversed. Each node is in independent equilibrium under the load Fh^2 and the tensions of the 4 string segments are tied to the node. For node Z_c, in equilibrium,

$$\begin{aligned} \Sigma f_z &= 0, \quad Fh^2 + \Sigma T_k \sin \alpha_k, \qquad k = a,b,r,l, \\ \Sigma f_y &= 0, \quad T_a \cos \alpha_a + T_b \cos \alpha_b = 0 \\ \Sigma f_x &= 0, \quad T_r \cos \alpha_r + T_l \cos \alpha_l = 0 \end{aligned} \tag{16}$$

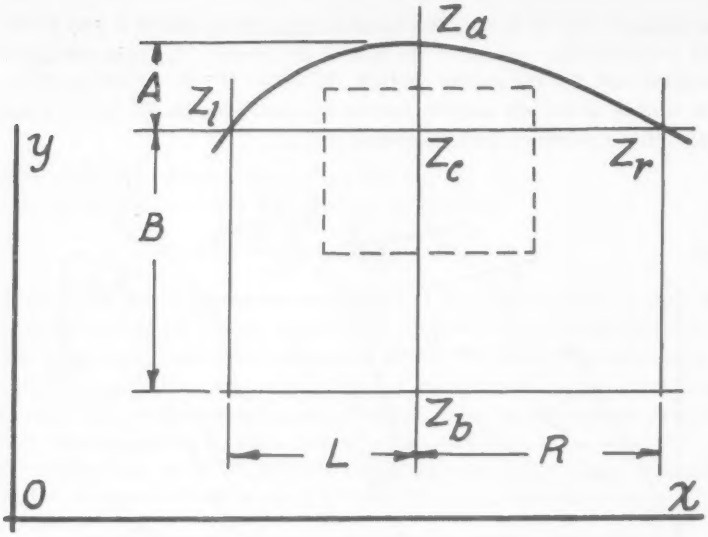

FIGURE 4. An irregular star.

The weights over the pulleys, W_{cx}, and W_{cy}, must obey EQUATION 17;

$$W_{cx} \cos \alpha_{cx} = W_{cy} \cos \alpha_{cy} = T_o = \tau h \tag{17}$$

The weights are adjusted at the pulleys to obtain τ constant per unit width in the projection on the xy plane of the string tension at the pulley. The tension in any string segment will be

$$T_k = \frac{\tau h}{\cos \alpha_k} \tag{18}$$

It follows, from EQUATION 16, that

$$\begin{aligned} T_a \cos \alpha_a &= -T_b \cos \alpha_b = T_o = \tau h \\ T_r \cos \alpha_r &= -T_l \cos \alpha_l = T_o = \tau h \end{aligned} \tag{19}$$

and, from the first of EQUATION 16,

$$Fh^2 + \tau h \left[\tan \alpha_a - \tan \alpha_b + \tan \alpha_r - \tan \alpha_l = 0\right. \tag{20}$$

or

$$Fh^2 + \tau [Z_a + Z_b + Z_r + Z_l - 4Z] = 0 \tag{21}$$

EQUATION 21 is the first approximation in the form of finite differences of the second order, for increments of length h, to the partial differential equation of Poisson (EQUATION 22):

$$\frac{F}{\tau} + \frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2} = 0 \tag{22}$$

The same values for Z_c at the nodes for the string net are obtained by Southwell, using his method of relaxation.[7-11]

Regular and irregular stars. The node Z_c has 4 strings of equal length h in projection on the xy plane. It is called a regular star. At the border, one or more segments of a star will often be shorter, and the equation of equilibrium must be modified. The mean force at node Z_c (FIGURE 4) is now $F(A + B)(R + L)/4$, and the mean values of tension will be $T_y = \tau(A + B)/2$ and $T_x = \tau(R + L)/2$; the equilibrium equation for the irregular star (FIGURE 3) will be

$$F\frac{1}{2\tau} + \frac{Z_r}{R(L+R)} + \frac{Z_l}{L(L+R)} + \frac{Z_b}{B(A+B)} + \frac{Z_a}{A(A+B)} - Z_c\left[\frac{1}{RL} + \frac{1}{AB}\right] = 0 \quad (23)$$

In a string net it is possible, but for the fact that it would complicate things, to change the tension at an irregular star. By using the same tension right through the irregular star, the equation of equilibrium becomes

$$F\frac{(A+B)(R+)}{4\tau h} + \frac{Z_r}{R} + \frac{Z_l}{L} + \frac{Z_b}{B} + \frac{Z_a}{A} - Z_c\left[\frac{1}{R} + \frac{1}{L} + \frac{1}{B} + \frac{1}{A}\right] = 0 \quad (24)$$

To balance the net. The string net will automatically solve all the equations for Z values of the net, one for each node (EQUATIONS 21 and 24), no matter how many, if the net is properly balanced. A net is balanced if τ is a constant for all strings and if the strings are adjusted so that they project orthogonally on the rectangular plot on the xy plane. The 2 conditions are necessary and sufficient to produce a balance of the net.

The convergence of finer and finer nets: limit value. If $z = z(x,y)$ is the exact mathematical solution of EQUATION 22 for a given boundary, assume that it can be expanded in a power series. Then, using Brook Taylor's expansion theorem, from the series expansion of z about a point z_c on the surface for $x = \pm h$, and $y = \pm h$, $h^2 \nabla^2 z$ can be written as

$$h^2\left(\frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2}\right) = z_a + z_b + z_r + z_l - 4z_c$$
$$-2\left[\frac{1}{4!}\left(z_x^{Iv} + z_y^{iv}\right)h^4 + \frac{1}{6!}\left(z_x^{vi} + z_y^{vi}\right)h^6 + \ldots\ldots\right] \quad (25)$$

The solution of EQUATION 21 for the Z values at the nodes, by string net for the same boundary, at the same scale, will be in contact with z at the boundary, but the nodes Z will not be on z at any other point. The amount of difference is found by experience to be less, as the number of strings is doubled, then redoubled. This result agrees with EQUATION 25; as h becomes smaller, the bracket in EQUATION 25 becomes smaller, and EQUATION 25 approaches the difference (EQUATION 21) after adding $Fh^2\tau$ to both sides of EQUATION 25. The derivatives of even and higher

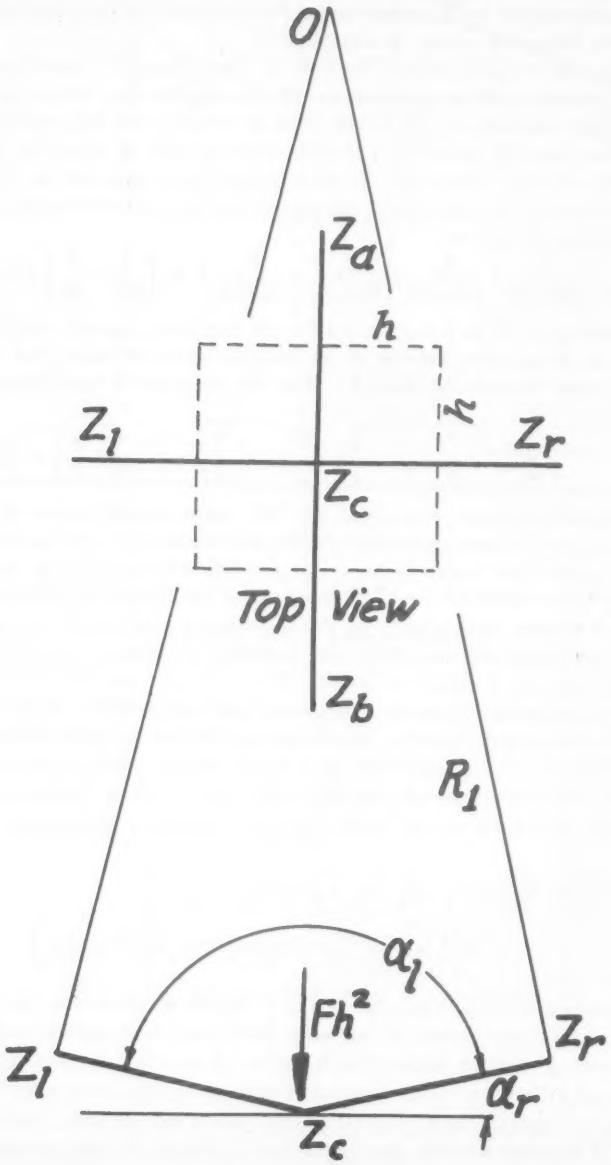

FIGURE 5. The soap-film net.

order may be small in value, suggesting that the series is limited to the second power; this would be indicated by the closeness to the parabolic form taken by a smooth curve through the nodes. In a previous paper, the nodes by string net were close to the exact mathematical solution, even for coarse nets; but the sum of the derivatives of the fourth, sixth, etc. order were all zero.[12] Franklin, Wiener, and Courant[13-15] discuss the limit value of nets. Of course the limit value at singular points does not exist.

The nonloaded net, or Laplace net. The equation of equilibrium for nonloaded or Laplace nets is EQUATION 21, EQUATION 23, or EQUATION 24 with $F = 0$. All the problems of stress distribution over the sections of shafts under torsion given in this report (FIGURES 14 to 19) were solved by the use of nonloaded or Laplace nets, form 2 (EQUATION 7) with boundary (EQUATION 8). But these nets were preceded by the construction of the nets, form 3, for the same problems, to the same scale (EQUATION 10). The agreement was within experimental error; but it was infinitely easier to double and redouble the number of strings, using form 2.

Symmetrical nets. One symmetrical part of the section of the shaft can be used as the string net. Since in all the shaft problems 2 keyways, diametrically opposite, were considered, one-quarter shaft was all that was needed. The planes of symmetry are at $x = 0$, and at $y = 0$. The additional necessary condition for balance of the net is the finite difference equivalent of $\partial z/\partial y = 0$ at all nodes on the x string of symmetry and for the corresponding condition for the y string of symmetry. For diagonal symmetry, or symmetry at repeated angles, the governing equation is that $\partial z/\partial n$, in a vertical plane normal to the plane of symmetry, is zero.

THE SOAP-FILM NET; THE SOAP FILM

The Soap-Film Net

If the strings in a string net were somehow held in contact at the nodes but with zero friction, then, for a full star, with vertical loading (FIGURE 5),

$$T_a = T_b = T_r = T_l = \tau_s h = W_{cx} = W_{cy} \tag{26}$$

in absolute value, and

$$\begin{aligned} \cos \alpha_a &= -\cos \alpha_b \\ \cos \alpha_r &= -\cos \alpha_l \end{aligned} \tag{27}$$

where τ_s is *the tension per unit width on the surface;* τ_s is *constant on the surface,* and *projects on the xy plane as a variable.*

From the geometry (FIGURE 5)

$$\begin{aligned} R_1 2 \alpha_r &= 2h \\ R_2 2 \alpha_a &= 2h \end{aligned} \tag{28}$$

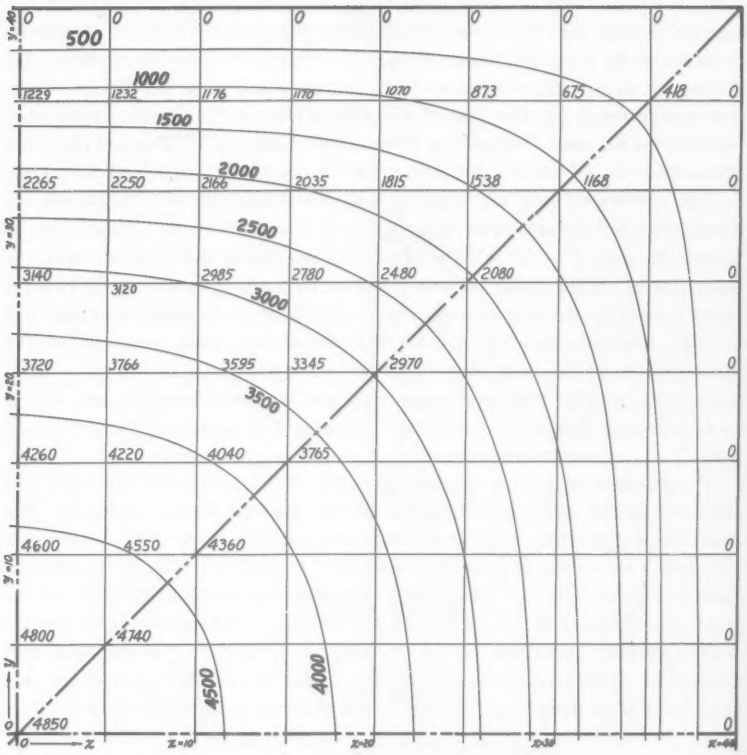

FIGURE 6. The Ψ net for a square shaft under torsion, with shear lines of equal values of Ψ.

For equilibrium, and, reversing the direction of the normal and of the net

$$\tau_s h \alpha_r + \tau_s h \alpha_a + Fh^2 = 0 \tag{29}$$

whence

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{F}{\tau_s} = 0 \tag{30}$$

EQUATION 30 is independent of the axes, hence it can represent the relation at any node of the net. EQUATIONS 28 are approximate, and accurate as $h \to 0$ as a limit, hence EQUATION 30 is the equation of a surface passing through a boundary, and having constant tension τ_s per unit width at every point of the surface, and having a load function $F(x,y)$ along the normal to the surface at every point, per unit area projected on

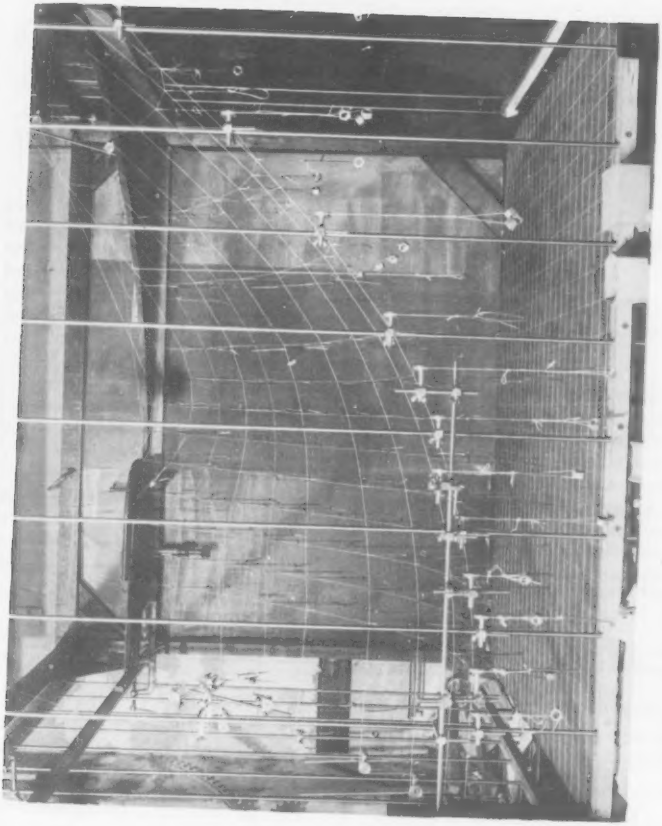

FIGURE 7. The Universal Frame for string nets.

a plane perpendicular to the normal at the point in question. The surface is called a minimal surface; it is the surface of minimal area across the boundary. For $F = \rho$, a constant, it would represent a soap film, with a constant $p/2\ \tau_s$, where τ_s is the surface tension of the film. The differential equation of a minimal surface in rectangular coordinates is

$$\frac{(1+p^2)\,t + (1+q^2)\,r - 2pqs}{\left[1+p^2+q^2\right]^{3/2}} + \frac{F}{\tau_s} = 0 \tag{31}$$

where the surface is solved for z, and

$$p = z_x,\ q = z_y,\ r = z_{xx},\ s = z_{xy},\ t = z_{yy} \tag{32}$$

If the boundary is constructed for a low-scale value of z, the gradient will be low everywhere, and p^2, q^2, and s will be small, and the EQUATION 31 will approach the equation of Poisson. With zero pressure dif-

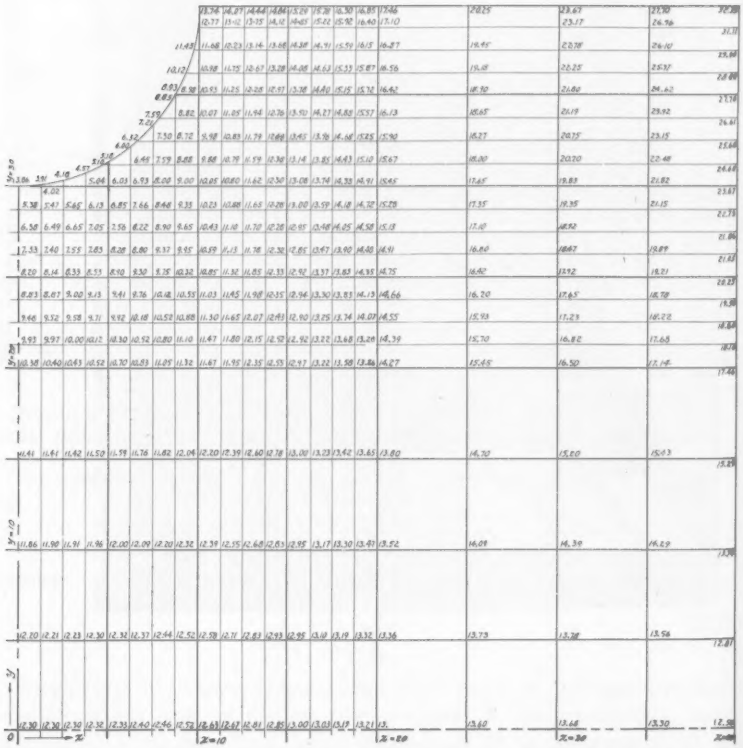

FIGURE 8. The ψ net for a square shaft, 80 in. by 80 in., with 2 circular keyways, 10 in. radius.

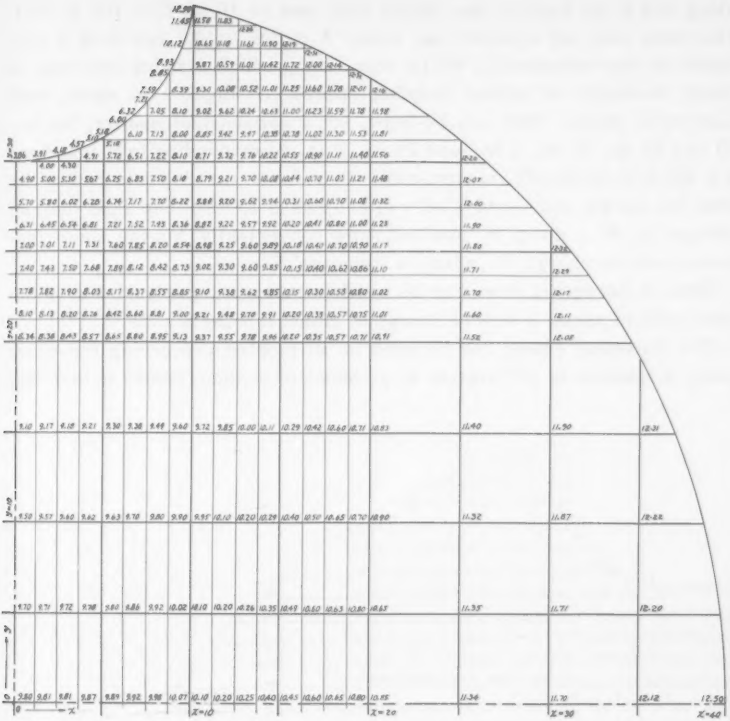

FIGURE 9. The ψ net for a circular shaft, 80 in. in diameter with 2 keyways, 10 in. radius.

ference on the 2 sides of the soap film, the surface will approximate the equation of Laplace.

The skillful experimentalists Griffith and Taylor[16] managed, with apparatus of superior design, to obtain accurate values for the stress concentration in shaft keyways. They used soap films with pressure difference p and form 3, and they also used, and preferred, films with zero pressure difference, form 2.[16-21]

THE UNIVERSAL FRAME FOR STRING NETS

FIGURE 6 is a photograph showing the Universal Frame used to house more than 50 nets. FIGURE 6 shows a net, loaded for form 3, Poisson equation, for a circular shaft in torsion. The shaft is 80 in. in diameter with 2 keyways 20 in. wide and 10 in. deep, with fillets of 5 in. radius in the corners. The one-fourth in. steel rods permit pulley holders to slide

along and to be fixed at any height from zero to 40 in. from the *xy* plot. The steel rods are spaced 5 in. apart. A pulley holder can hold a one-fourth in. bar horizontally, 4¾ in. long, along which 4 swing bars can be fixed, available at various lengths, spaced five-eighths in. apart, each carrying a pulley. Nets can be built, for a symmetrical quarter, for h = 40 in., 20 in., 10 in., 5 in., and 2½ in., ⅝ in. corresponding to $80/n$, where n = 2,4,8,16,32,64,128, respectively. This frame was built to house the nets for square and round shafts (FIGURES 5 to 19). The form may be changed to fit a group of sections more conveniently, but the major features need not change. It is truly a Universal Frame.

Nets of hexagonal form can be used by changing the position of the steel rods to permit 3 sets of strings to cross, forming a node.

The Universal Frame can be used in all problems involving the equations of Laplace or of Poisson: in problems of torsion, beams in bending,

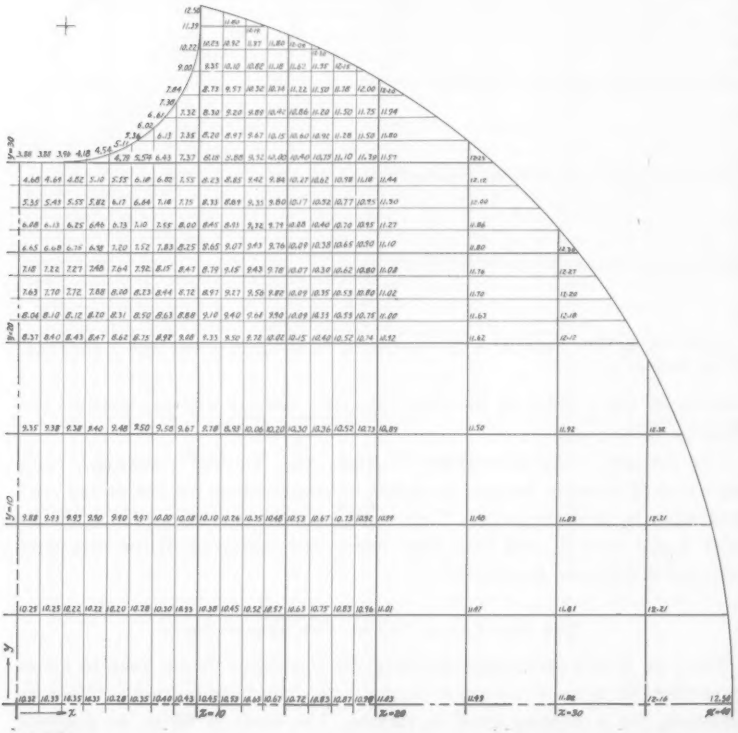

FIGURE 10. The ψ net for a circular shaft, 80 in. diameter with 2 keyways, 20 in. wide, 10 in. deep, with fillets of 7½ in. radius.

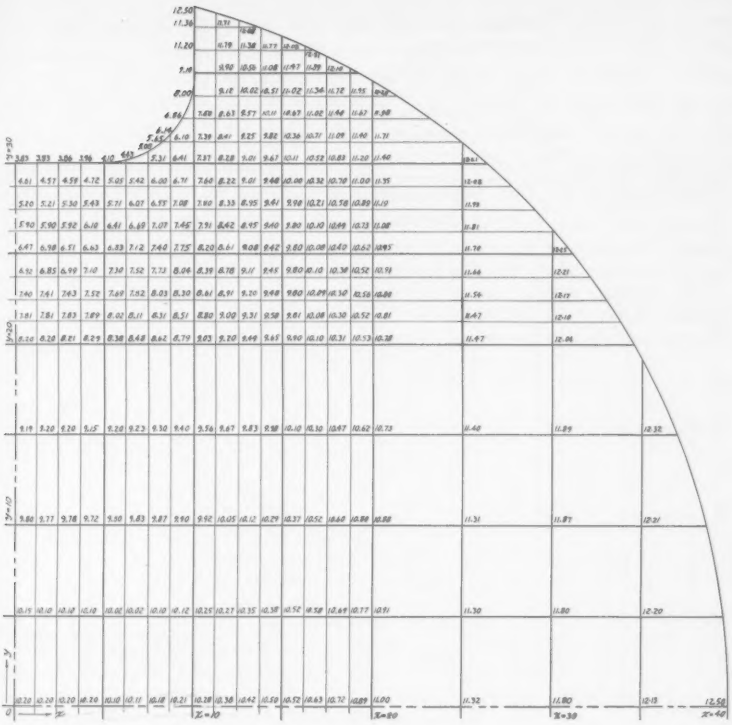

FIGURE 11. As in FIGURE 10, except for fillets of 5 in. radius.

heat transfer, potential distribution, fluid mechanics, and pressure distribution.

NETS THAT FORM PART OF THE REPORT

FIGURE 7 is a Ψ plot obtained from a loaded or Poisson net for a square shaft in torsion. Curves for equal values of Ψ are shown. All the nets that follow (FIGURES 7 to 19) were obtained by using form 2 (EQUATIONS 7 and 9) and the nonloaded net of Laplace. The scale for the ψ boundary is given in EQUATION 33.

$$\psi = .0124\,(x^2 + y^2) \tag{33}$$

From the plot ψ of the string net over this boundary, values of the derivatives (EQUATIONS 34) were obtained, from which the value of G, the gradient of the Ψ surface at the point was calculated,

$$\begin{aligned} \frac{\partial \Psi}{\partial x} &= \frac{\partial \psi}{\partial x} - .0248\,x \\ \frac{\partial \Psi}{\partial y} &= \frac{\partial \psi}{\partial y} - .0248\,y \end{aligned} \tag{34}$$

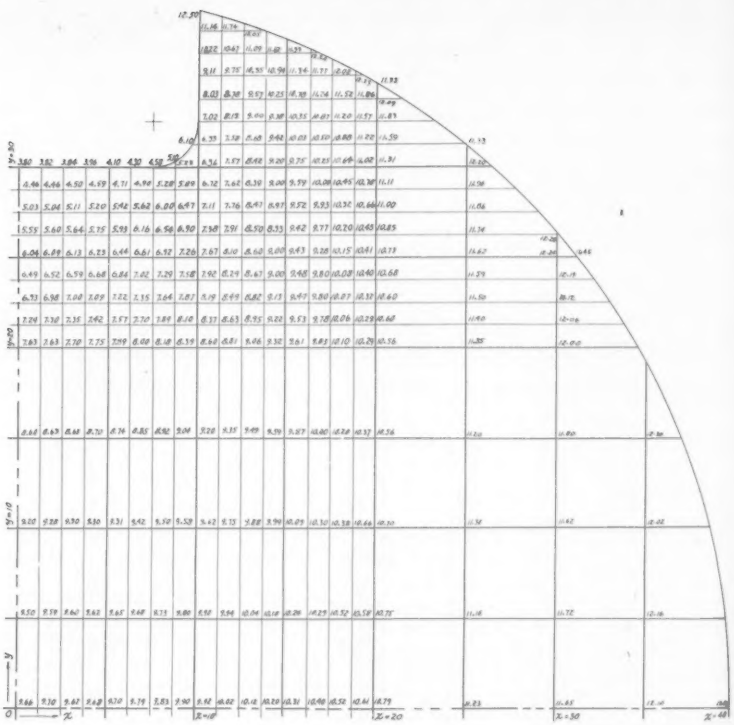

FIGURE 12. As in FIGURE 10, except fillets of 2½ in. radius.

The Scales Used

On the ψ plots (FIGURES 8 to 13) the readings are heights of the ψ node in inches, which plot is actually 7.35 in. above the zero for the ψ surface. The G plots (FIGURES 14-19) are based on the ψ plots (FIGURES 8 to 13), with sequence corresponding. The values given at the nodes of the G plot are the actual G values of the ψ net $\times$ 1000. To obtain the shear stress values at the nodes, multiply the given G values by 10, thus bringing these values into agreement with the stress values on the curves of constant stress.

Remarks

While the curves of equal stress agree well with the stress values at the border and at the keyway points, further study is required to locate the exact point on the keyway where the stress is maximum, as well as

its exact value. The soap film has the advantage of continuity, an advantage that is important for this very purpose. The stress rises rapidly in the neighborhood of this point; interpolation is not accurate. A finer net in the vicinity would help; further investigation is necessary in this connection. The stress in the keyway corner, with fillet radius zero, increased as the finer nets were used, which was to be expected since the stress is infinite for a sharp re-entrant angle. For the other values of fillet radius the stress approached a definite value.

ACKNOWLEDGMENT

It is a pleasure to acknowledge that this research was aided considerably by a grant from the Research Corporation, New York, N.Y.

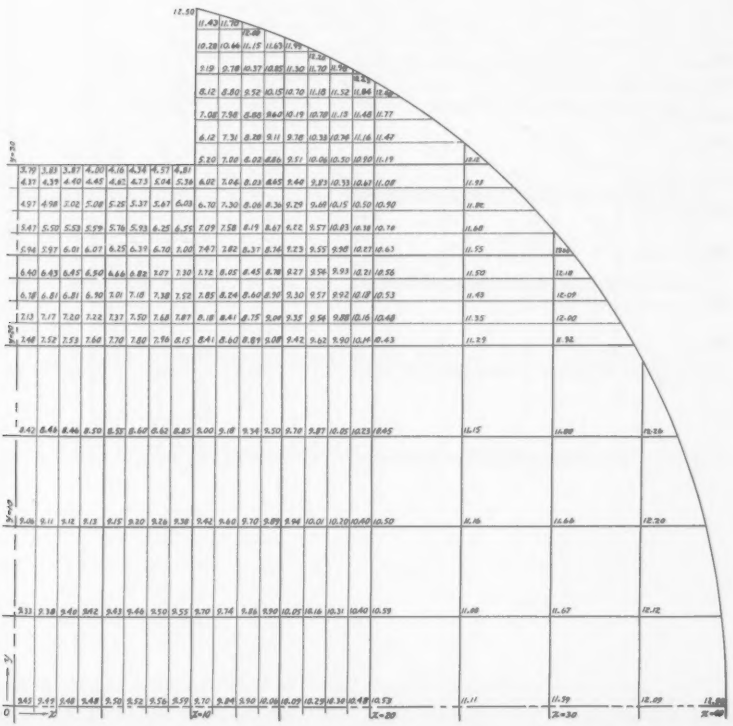

FIGURE 13. As in FIGURE 10, except fillets of zero inch radius.

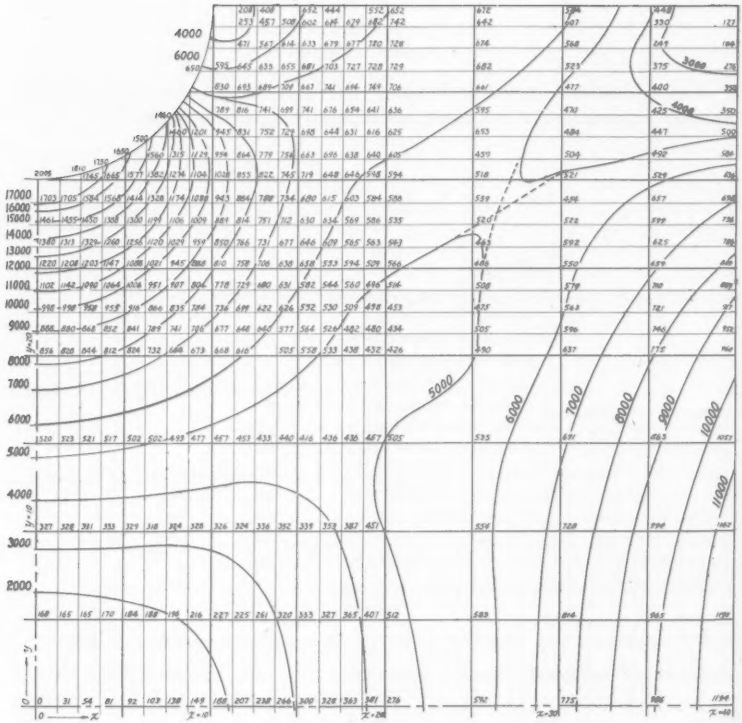

FIGURE 14 The G net, and stress distribution for a square shaft, the ψ net of which is FIGURE 8.

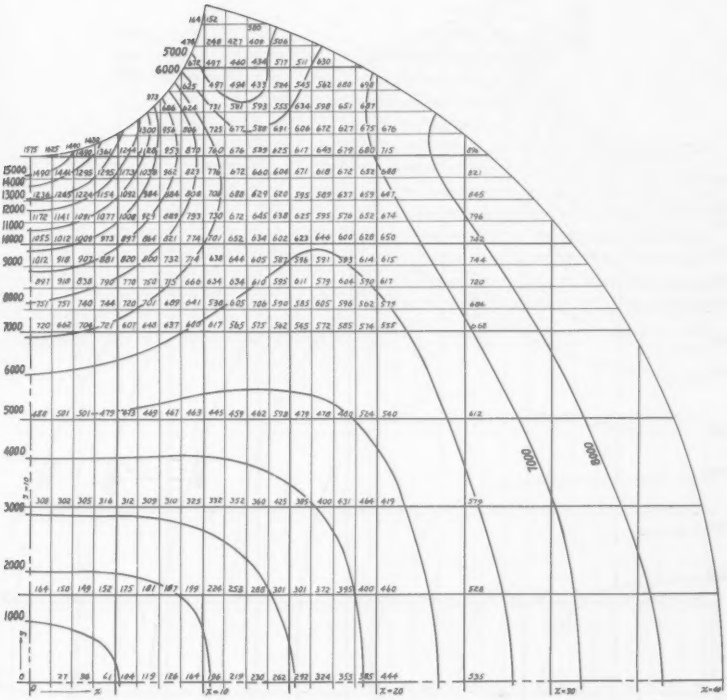

FIGURE 15. The G net and stress distribution for a circular shaft, the ψ net of which is shown in FIGURE 9.

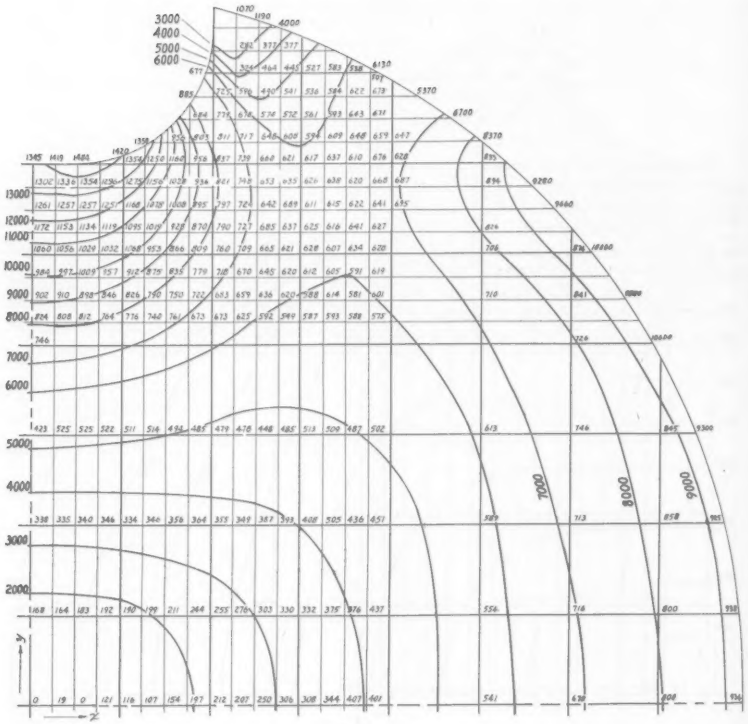

FIGURE 16. The G net and stress distribution for a circular shaft, the ψ net of which is shown in FIGURE 10.

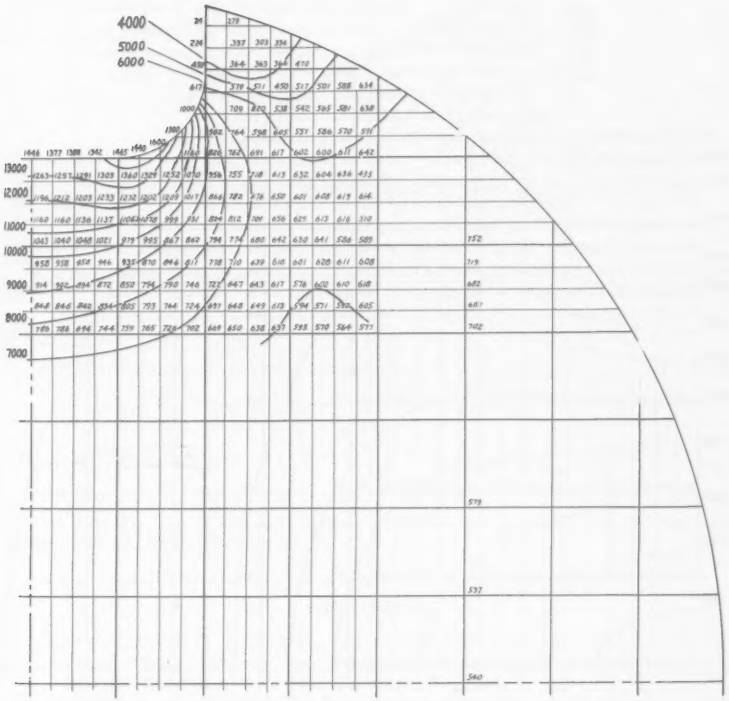

FIGURE 17. The G net and stress distribution for a circular shaft, the ψ net of which is shown in FIGURE 11.

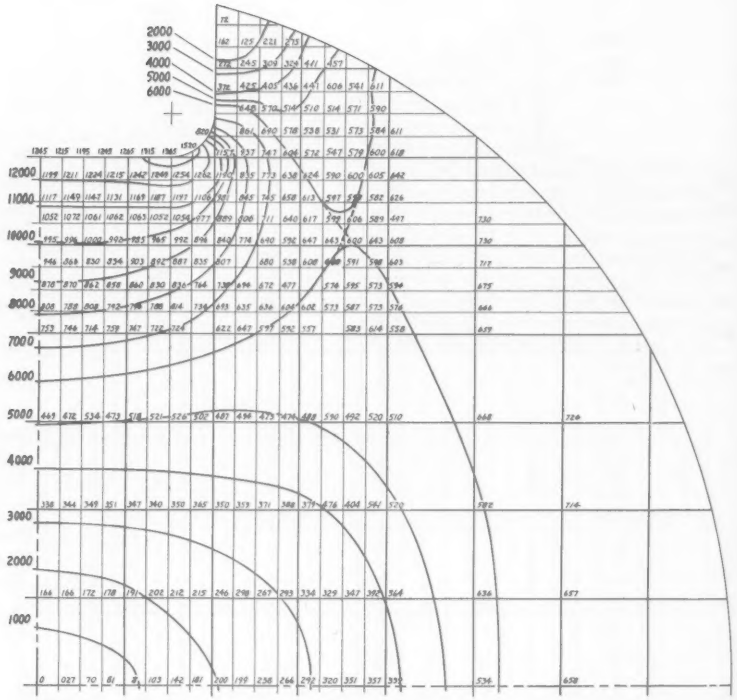

FIGURE 18. The G net and stress distribution for a circular shaft, the ψ net of which is shown in FIGURE 12.

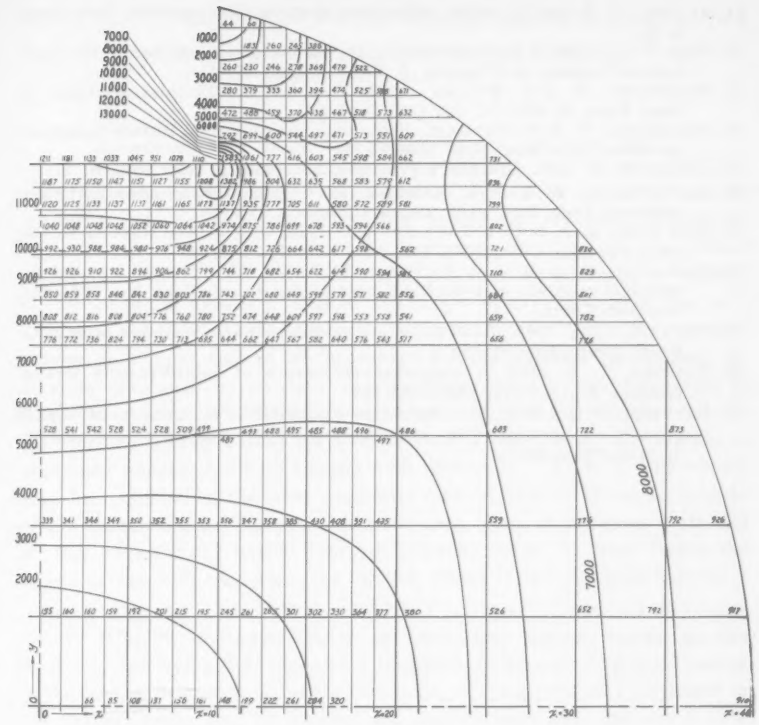

FIGURE 19. The G net and stress distribution for a circular shaft, the ψ net of which is shown in FIGURE 13.

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SECTION OF ANTHROPOLOGY

JEHOVAH'S WITNESSES AND THE VALUES OF AMERICAN CULTURE*

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This discussion represents an attempt to project the teachings and the activities of the religious movement known as Jehovah's Witnesses against the total background of contemporary culture in the United States. This discussion does not aim to examine the accuracy or validity of the Scriptural exegesis adopted and taught by this movement, nor is it in any way concerned with theological controversy. A student of Jehovah's Witnesses cannot fail to be impressed by the extreme earnestness of purpose displayed by members of this group and by their dedication to their faith. Jehovah's Witnesses definitely deserve to be approached in the spirit of George Santayana's remark to the effect that "the feeling of reverence should itself be treated with reverence" (White[1]). One should also be reminded of the wise pronouncement of Justice Owen J. Roberts of the United States Supreme Court: "In the realm of religious faith and in that of political belief sharp differences arise. In both fields the tenets of one man may seem the rankest errors to his neighbor" (Pike[2]).

As in the cases of Mary Baker Eddy's Christian Science and of Joseph Smith's Church of Jesus Christ of Latter-Day Saints, known as the Mormons, Jehovah's Witnesses is a religious movement completely native to the United States. Most of its followers, although not all, are found in the United States, and its founder and leaders have been natives of this country. Thus, in analyzing the teachings of this movement and in speculating on the nature of their appeal to their followers, one is justified in regarding this sect as possessing a diagnostic value of some importance to the student of American social and cultural dynamics.

A complete history of the movement would leave little room for analytical remarks. Under the circumstances, a bare outline of basic facts and chronology must suffice. The movement owes its existence to Charles Taze Russell, subsequently known as Pastor Russell. He was born in Allegheny, Pa., in 1852 of Scottish-Irish ancestry. As a young man he was influenced successively by Presbyterians, Congregationalists, the Y.M.C.A., and the followers of William Miller, known as Millerites, Adventists, or Seventh-Day Adventists. Dissatisfied with the existing doctrines, young Russell turned eventually to an independent study of the Scriptures and, in collaboration with a group of friends and followers, he organized a Bible study group in Pittsburgh, Pa. This was the nucleus of the movement known today as Jehovah's Witnesses. Actually this last name was not adopted formally until 1931 by Pastor Russell's successor,

*This paper was presented at a meeting of the Section on October 22, 1956.

Joseph Franklin Rutherford, better known as Judge Rutherford. The first pamphlet by Pastor Russell appeared under the title *The Object and Manner of the Lord's Return* in 1874. In 1881 there appeared another small booklet, *Food for Thinking Christians*, summarizing the basic beliefs of the new group. No one could have predicted at that point that these modest beginnings would be followed by a deluge of doctrinaire and missionary publications running to millions of copies printed in nearly 80 languages.

There is no doubt that the original impulse imparted to this movement and its initial success should be credited to the exceptional perseverance of its founder and to his charismatic personality. Its followers were fortunate in finding a similarly dynamic and dedicated successor in the person of Judge Rutherford, who was to direct its activities for the 26 years between 1916 and 1942. Judge Rutherford was born at Booneville, Mo. in 1869, of farming stock. For a brief period he practiced law in his native state. In addition to religious enthusiasm he brought to the organization great administrative and propagandist gifts. He was also a prolific writer, and his numerous books and pamphlets have been translated into many languages.

Judge Rutherford died in January 1942 and, shortly thereafter, the controlling organization of Jehovah's Witnesses elected Nathan Homer Knorr as head of the movement. Mr. Knorr, who was born in Bethlehem, Pa. in 1905, became associated with the movement as a very young man, reached his position of leadership from the ranks, and proved his ability at various successive levels of organizational work.

The organization and the very concept of organization are dear to the hearts of Jehovah's Witnesses. "Every creature in the Universe must become either a part of the organization of God or a part of the organization under the control of Satan" (Rutherford[3]). God's Organization in Heaven (also referred to as Jehovah's Heavenly Kingdom or the New Jerusalem) is a distant realm where Jehovah God presides over countless spiritual creatures including angels, archangels, and cherubim, and where, in 1914, Christ was installed as King.

The earthly counterpart of God's Organization is believed to be identified with the organization of Jehovah's Witnesses. In this connection it is important to make clear the fact that the movement claims spiritual ancestry far beyond the local American manifestation by Pastor Russell and Judge Rutherford. Presbyter Arius of Alexandria (A.D. 256 to 336), exponent of a Christological viewpoint known as Arianism; the 12th century Waldenses, followers of Peter Waldo (fl.1173-1179) of Lyon in France; the 15th century Lollards, followers of John Wycliffe (1320?-1384) of England: all these and many others are considered to constitute a spiritual lineage extending back to King David, to Moses, to Abraham, to Noah, to Enoch and, ultimately, to the first human pair created by Jehovah God to live forever under his theocratic rule in the Garden of

Eden. Thus, practical and pedestrian as the daily routines of organized functioning are bound to be in this world, the organization of Jehovah's Witnesses is pervaded by the proud conception of its mystical role as promoter of a divine mission and as inheritor of a sacred truth.

The members of this movement do not claim that God's word was revealed to only a few. In their view, this message has been made available to all those who have been reached by the Bible, both the Old and the New Testament – and these believers constitute a sizable portion of past and living mankind. Misled by Satan and his hosts and under the influence of "false" religions, men either ignored the Bible or gave it an incorrect interpretation. Consequently, although Jehovah's Witnesses lay claim to a monopoly on truth, they reject the charge of superciliousness on the ground that their attitudes represent no more than an expression of their good will, which they show by studying the divinely inspired Scriptures and recognizing their true and lucid meaning. All of their printing and preaching activities are dedicated to the end of sharing with the rest of men what is to them the self-evident and unequivocal Biblical message.

Consistent with their basic premises, Jehovah's Witnesses never hesitate to denounce openly and aggressively all other religions, including all other forms of Christianity. They use the term "Christendom" to allude to all allegedly "false" forms of belief and worship, and reserve the word "Christianity" for themselves and their spiritual predecessors and sympathizers. Interfaith fraternization they condemn as an expression of lack of conviction and of the desire to compromise and to achieve peace at any cost. This condemnation of all established religions extends even to the concept of a "natural religion." On the ground that, since men live in different environments, face different problems, and lead different ways of life, "the development of natural religion is bound to differ in various sections of the earth" (*What Has Religion Done For Mankind?*[4]). This last argument is not in conflict with the views of anthropologists. In the presence of supernaturalistic phenomena claimed by other faiths, Jehovah's Witnesses tend not so much to doubt and question the substantive reality of such occurrences as to ascribe them to the activities of Satan and his underlings. They apply the same interpretation to the power of communicating with the dead claimed by spiritualists, and they view the gods of Hinduism, as well as the mythological creatures of classical antiquity, in the same light.

This condemnation of other religions is not limited to matters of faith, but includes various religious attitudes as well. Thus, they are unequivocal in rejecting (1) the "peace-of-mind" and "peace-of-soul" varieties of faith; (2) appeals to religion made in the name of mental therapy or physical healing; (3) religious sentimentalism exemplified by such jukebox records as "Are You Friends with the King of Friends?" and (4) religious revivals based on what they call the emotional shock treatment.

It is important to understand that, within their basic premises, Jehovah's Witnesses view themselves as a thoroughly rationalistic religious movement. They discourage individual mysticism, as well as group emotionalism; they invite conversion, not "on faith", but on the basis of reasoned textual interpretation alone. This didactic and bookish orientation undoubtedly operates as a major factor in the selection of potential converts. It is remarkable that so many middle-class Americans of our time have chosen to follow a movement of faith based entirely on Biblical exegesis. One should add at this point that places of worship in which Jehovah's Witnesses congregate are devoid of all pictorial and sculptural adornments; that hymn singing and church music play a secondary role; and that the verbal patterns followed by their preachers and discussion leaders seem to avoid oratorical effects and emotional undertones.

This is not to say, however, that the message of Jehovah's Witnesses is without impact on human emotions, as testified by their persistent references to the true, substantive, and active existence of Satan and to his numerous spiritual and human underlings, and by their firm belief that the world in which we live is in Satan's hands and headed for an imminent Armageddon, the Battle of the Ages. All these beliefs make demonstrative emotionalism superfluous. There is no need to dramatize the already dramatic. Only an incomplete faith calls for nonrational props. What are Satan's role and origin as they are understood by Jehovah's Witnesses? When Jehovah God created Adam and Eve to enjoy immortality in the Garden of Eden, he assigned one of his spiritual creatures (sons), the Covering Cherub Lucifer, to watch over the first human pair. Lucifer was a perfect creature, but allowed himself to be corrupted by envy and vanity. In order to recruit subjects he seduced Eve and through her Adam into disobeying God's command and tasting the forbidden fruit (interpreted literally as a fruit of a tree). This sin of disobedience brought death and corruption into the world. Only Christ's voluntary self-sacrifice (referred to as Ransom) restored man's right to immortality. This immortality, however, will be enjoyed, not in heaven, but on earth, and not by all, but only by those who will live through the Battle of Armageddon and who, after a reign of a thousand years under Christ, will be judged worthy of a deathless existence in a perfect world.

Jehovah's Witnesses deny the immortality of individual human souls, as well as the very existence of a soul separate from the body. The dead are asleep, but they will be awakened after the Battle of Armageddon and given a "second chance." Those who fail will be returned to ultimate death without awakening. A special reward is in store for a small group of 144,000 particularly worthy servants of Jehovah of all ages, who will be taken into the Kingdom of Heaven for an eternity at the throne of God. These persons are known as the Little Flock.

To return to Lucifer's fate, we find him, after the episode in the Garden of Eden, in the role of and under the name of Satan (the "Ad-

versary" in Hebrew), the Deceiver, the Evil One, Serpent, or the Devil (from the Greek *Diabolos*). By Jehovah's decision Lucifer is left free to contend for human minds with the forces of light. Even the Heavenly Kingdom was open to him until 1914, when Christ cast him out and thus inaugurated the Second Advent.

At the Battle of Armageddon, Satan and his hosts will be defeated, but not yet destroyed. After a period of one thousand years they will have another opportunity to contend for human allegiance, whereupon they and all their cohorts will meet with a definite end which will, in a sense, conclude the drama of the ages and inaugurate an eternity of felicity in this world.

This synoptic account of the image held by Jehovah's Witnesses of the past, the present, and the future, is not peripheral to their teachings, nor in any manner symbolic. This is the realm in which they live, even though surrounded by the more widely shared trappings of our social reality. Needless to say, such views tend to isolate their followers from part of the social environment. As a matter of fact, members of this movement spend most of their free time in study groups, meetings of worship, and volunteer services, and they lead a somewhat encapsulated existence. As a rule they do not vote or take active interest in politics. They also de-emphasize social reforms as superfluous in view of the imminence of Armageddon, which is to bring into being a world without jails, hospitals, famine, old age, or death.

The social isolation of Jehovah's Witnesses is sharpened by their withdrawal from such collective experiences as the celebration of Christmas (which they consider a nonscriptural pagan ritual). Similar psychological effects grow out of their rejection of the sign of the cross and the traditional account of the crucifixion. They claim that the cross is an ancient Egyptian, that is, a pagan, symbol and that Christ died on the torture stake, that is, a tree without a crossbar.

These remarks concerning the isolating effects of the beliefs and practices of Jehovah's Witnesses can be inverted, of course, to mean that here is a movement that appeals to the alienated social strata (A. J. Toynbee calls them the "internal proletariat") in our population. In spite of the many channels for social and economic mobility provided by the politico-economic system prevailing in the United States numerous people find themselves relegated to social and economic mediocrity. Life rushes by and leaves behind these less fortunate people. This is not so much a reference to poverty as to a limited participation in the over-all scheme of success and its visible material rewards. There is no doubt that the majority of Jehovah's Witnesses "live on a humbler side of life" (Cole[5]).

It is legitimate to suggest that some of the negative and aggressive elements inherent in the attitude of Jehovah's Witnesses toward the "false" religions of mankind and their dramatic vision of semiuniversal

annihilation at the cosmic Battle of Armageddon are not unrelated to their feelings of frustration and alienation. In studying the movement one is reminded of Friedrich Nietzsche's insights into the mentality of the early Christian in the classical world, as well as of Max Scheler's analysis of the relationship between social resentment and the genesis of values (Nietzsche[6] and Scheler[7]).

It is important to reiterate that the frustrations and alienation widely experienced today should not be understood in crudely economic terms alone. Jehovah's Witnesses appear to harbor a more deep-seated feeling of discontent that may be traced to the traumas inflicted on man by the speed of the processes of social and cultural change. This attitude is not unlike the reaction of a diffident and hostile small town to the modernism and sophistication of a metropolitis. Jehovah's Witnesses are thus opposed to the far-reaching recent changes in the status of women. They stress the role of Eve in the fall of Adam and the allegedly central role of women in the functioning of all "false" religions. In the realm of theology, they reinstate the central position of God the Father, and reduce Christ to the subordinate role of an obedient Son. Speaking in terms of human society, this position can be viewed as an indirect protest against the filiocentric orientation of modern culture.

Another manifestation of the opposition of Jehovah's Witnesses to modern practice is, of course, to be found in their generalized anti-scientism. Thus, they repudiate the use of blood transfusion and of animal serum for therapeutic purposes. They also take a very strong stand against the teachings of Charles Darwin and of his contemporaries and successors. In so doing they heap sarcasm upon the allegedly unintelligent or even dishonest biologists, and they sympathetically quote from specialized literature excerpts that appear to support their anti-evolutionary beliefs.

Carrying this analysis a step further, one has the impression that the teachings of Jehovah's Witnesses meet the demands of their followers, not just as an expression of cultural protest but, also, as a more assertive and comprehensive philosophy of life than modern philosophers and scientists feel inclined to offer.

As a result, our culture has given up the ancient preoccupation with the problem of Evil in general and has substituted specialized research, for example, on economic cycles, crime, or suicide. This has occurred at the very time when the scope of historical events has evolved a questioning attitude in the masses. Jehovah's Witnesses, perfect reductionists as they prove to be, meet the public demand for a dependable world view by reducing the complexity of world events to the common denominator of Satan's struggle against the will of God.

From the point of view of cultural theory it is important to realize that the teachings of Jehovah's Witnesses offer nothing totally alien to our tradition and few truly new elements. What is new is the combination

of components and the distribution of emphases. Otherwise, it is obvious that the founders of the movement had drawn on the old cultural heritage and had attempted to revitalize some of its obsolescent features. The strength of the movement lies in its reliance on this shared cultural heritage or, one might call it, our collective cultural commitments.

The strongly selective appeal of the movement makes its further growth a questionable prospect. Not all socio-culturally alienated elements with a need for a definitive world view will be satisfied with exegetic sophistry and unemotional didacticism. Thus, there will be room for similar movements offering different patterns of personality gratifications. It is also legitimate to believe that, with the march of time, successive generations of Jehovah's Witnesses will make peace with the world (the French call this process *s'embourgeoiser*) and will give their prophecies a more symbolic and a less immediate connotation.

As it is, one must not forget that, their dramatic teachings notwithstanding, the majority of Jehovah's Witnesses are kind and friendly middle-class people. They take obvious delight in huge open-air meetings, which they organize expertly. Like our businessmen, they believe in advertising and even in emphasizing their teachings by slogans. As for their vision of heaven on earth, it is couched in terms of flowers and children, murmuring brooks, and groves of palm trees and, as such, it would please the most undemanding lover of poetry. Nevertheless it is important to realize that the vision of Jehovah's Witnesses is not one more "peace-of-mind" religious movement and that their apocalyptic faith is an echo to the unresolved issues of our culture.

Interesting parallels appear between the world view of Jehovah's Witnesses and the beliefs underlying the so-called *nativistic* movements observed by anthropologists in east Africa, New Guinea, and among American Indians. Though all of these differ from one another, they all concur in idealizing the legendary past, in repudiating the evils of modern civilization, in predicting a cataclysmic undoing of the existing world order and in looking forward to a supernaturally sponsored era of felicity on earth. In the case of *nativistic* movements, we are in the presence of a defensive intercultural reaction of small preindustrial societies overwhelmed by the dislocating impact of a foreign civilization. The protest of Jehovah's Witnesses comes, of course, from within our own world. Nevertheless the ideology of this movement has roots in the "preindustrial" tradition embodied by the Scriptures and appeals strongly to segments of our population alienated by the complexity and the ambiguities of modern civilization.

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DIVISION OF MYCOLOGY

THE BLIGHT, THE BLIGHTER, AND THE BLIGHTED*

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The Blight

The story of the late blight of potatoes began in Europe more than a century ago. Although the disease had been reported in North America a few years before 1845, it was not until the great epidemic in that year that late blight commanded the alarmed attention of an entire continent. For two successive seasons the potato fields of Ireland were destroyed by a new and mysterious agent that not only killed the foliage but rotted the tubers in the ground and in storage. The misery and famine that followed the epidemics constitute one of the most tragic episodes in the history of man. Of a population in Ireland of eight million, over one million died in the famine and one million and one half emigrated.

Although the disease has not caused other disasters of such major proportions, through the years it has become established in most of the potato-growing areas of the world, where it is a constant threat and occasionally causes great hardship. The condition has become a world-wide problem in the production of a basic food crop. The preventive spraying of potatoes is now standard practice in successful potato production wherever the blight is a menace. This disease causes annual losses that may be figured in hundreds of millions of dollars, because one must charge to it not only the direct crop losses, but also the cost of expensive control measures.

In Mexico, potato production is limited mostly to areas and seasons that do not favor the development of late blight. The plants thus escape the disease. In that country low yields make the potato a luxury vegetable rather than a staple food. Higher yields obtained through the use of expensive irrigation during the dry season do not change this situation substantially.

The first experiments with potato production during the summer rainy season showed that spectacular yields can be obtained if the plants are adequately protected against late blight. However, the potato can become a basic food crop in Mexico only when high yields are obtainable without the use of expensive sprays. Such yields will be possible only when a commercially acceptable blight-resistant potato variety is available to the Mexican farmer.

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The Blighter

As the potato fields blighted in Ireland and the grim consequences slowly descended on the people, the cause of this calamity became the subject of much conjecture and some scientific observation. Keen observers soon noted the constant association of a small fungus with the dreaded blight. Though the fungus was accurately described and recognized by some as the probable cause, not until 25 years later did the great German mycologist, Anton DeBary, prove conclusively that it was the pathogen. He observed the germination of the sporangia, inoculated healthy foliage and tubers, watched the lesions grow, and recovered the fungus from the withering plants. He gave the fungus the name of *Phytophthora infestans* (Mont.) DBy. and, for many years, his careful studies constituted our full scientific knowledge of this important species.

The wild Mexican species *Solanum demissum* Lindl. is practically the only source of blight resistance that has been used by plant breeders. Four "major" genes for blight resistance in this species have been described, and these genes have been isolated in selections from crosses of *S. demissum* x *S. tuberosum.*[1] A series of differential clones carrying these genes singly or in combination has been established, and it forms the basis for identifying 16 races of the pathogen.[2]

Since *S. demissum* is native to central Mexico, and since this area has been suggested as the probable site of origin of the potato blight,[3] it was of great interest to study the blight situation there. Investigation promptly showed there was a highly specialized population of races prevalent in the field,[4] including some races that could cause lesions on all clones of *S. demissum* that were tested. In 4 years of trials, no tuber-bearing *Solanum* immune to *P. infestans* was found. This result was not entirely unexpected, because the races of the pathogen prevalent in central Mexico developed through many hundreds of years of natural association with the wild, resistant species.

During the past 4 years several hundred cultures of *P. infestans* have been isolated, chiefly from diseased material collected in the field at the Chapingo and Toluca experiment stations in the State of Mexico. In 1953 a set of 6 of these Mexican isolates of *P. infestans* was sent to the United States Department of Agriculture, Washington, D. C. Early in the summer of 1956, Mannon Gallegly, of the University of West Virginia, Morgantown, W. Va., reported to us that certain of the Mexican isolates would mate and form oöspores freely with cultures that had been isolated in the United States. During the summer and fall of 1956, in collaboration with Gallegly, we paired 145 isolates with each of 2 strains (isolates No. 43 and No. 63) which formed oöspores when mated (FIGURES 1 and 2). Fifty-nine of these isolates formed oöspores when paired with isolate No. 63, and did not form oöspores with isolate No. 43. Eighty-six iso-

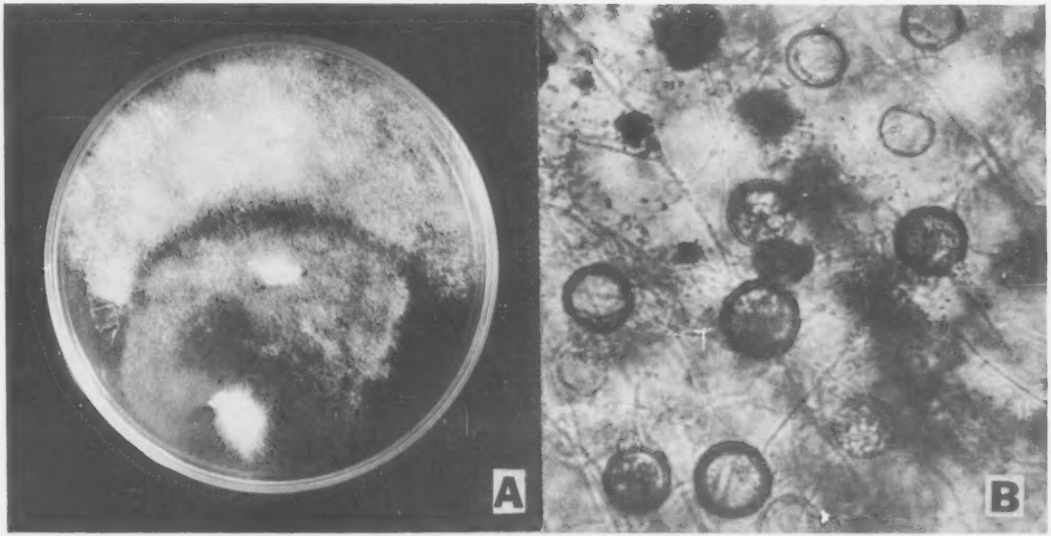

FIGURE 1. Production of oöspores by *Phytophthora infestans*. (A) The "unknown" isolate under test is planted at the center of the plate. The 2 isolates planted in the upper and lower parts of the plate are of different sexual strains, that is, they will form oöspores when paired. The "unknown" is repelled by the upper isolate and is considered to be of the same sexual strain. It is merging with the lower isolate and is forming oöspores with it. (B) Oöspores produced in culture (photograph by Leopoldo Servín).

lates formed oöspores when paired with isolate No. 43, and did not form oöspores with isolate No. 63. Twenty-one isolates of *P. infestans* from the United States were all of the same sexual strain, forming oöspores when paired with isolate No. 43, none with isolate No. 63. Many more isolates must be tested to determine whether the existence of a single sexual strain may be a reason explaining why oöspores have been found so rarely in the United States and elsewhere.

Two sexual strains of the fungus are prevalent in central Mexico; when an isolate of one of these strains is paired with the other strain, oöspores are produced abundantly. Oöspores have been found twice in diseased leaf tissue collected from blighting check varieties in the field at Toluca. It is considered almost certain that these sexual spores also occur in the blighted tissues of wild species. The situation with regard to physiologic races in Mexico is thus greatly complicated by the occurrence of a functional sexual stage of the pathogen. It is not difficult to explain why so many specialized races of pathogens are prevalent in the high valleys of Mexico, where the pathogen is able to breed freely and propagate on a number of resistant wild species.

Two important implications follow from this discovery for those interested in blight resistance. First, for central Mexico, at least, it implies the futility of making selections the resistance of which is effective only against certain races. Second, it implies a valuable stability in the high level of field resistance found in the wild species, a stability that has allowed them to survive a long natural association with the many races of the pathogen.

The Blighted

Although an exhaustive search for a blight-resistant commercial potato variety has been conducted for more than a century, we still do not have one that can be grown without protection in areas where late blight is prevalent. New races of the pathogen have appeared and blighted the "resistant" selections a few years after their introduction. The history of temporary success and subsequent disillusion is very discouraging; in Mexico no immune *Solanum* species has been found. However, the prospects are far from hopeless. The discovery of new races of the pathogen has pointed out the reasons for previous failures, and it now suggests that new approaches are required to solve the problem.

Although no clone of *S. demissum* has been found to be immune, the species does have a high level of field resistance that would be invaluable in a commercial potato variety. This field resistance is characterized by slow-spreading lesions in which sporulation is sparse. Usually there are only a few lesions per plant, and these tend to be on the older, lower leaves. It is this type of field resistance that has enabled *S. demissum* and other wild species to survive in Mexico.

FIGURE 2. Oöspore (photograph by Leopoldo Servin).

FIGURE 3. Field-resistance test at Toluca, Mexico, made in 1956. (A) View of plot in which introduced seedlings were tested; more than 98 per cent were blighted and killed. A few of the most resistant plants were selected. (B) Resistant selections made the previous year are planted in single rows (left). The two susceptible check rows are the dead Bintje (indicated by arrow) and the dying Kennebec (right).

Low levels of field resistance occur in such varieties as Sebago, Alpha, and Voran. Having found that these varieties can be sprayed somewhat less thoroughly than more susceptible varieties and still be adequately protected, Mexican farmers have made practical use of this resistance. If the degree of field resistance shown by *S. demissum* could be incorporated in a commercially acceptable potato, protective sprays against late blight probably would be unnecessary. Perhaps this goal can be approached by making selections in the uniquely severe blight environment in Mexico.

Since 1953, many thousands of clones of potatoes have been tested in the field at Toluca. These have been sent to us by cooperators in many countries. Each year a few promising selections are made (FIGURE 3). The selections have survived a blight test perhaps unequalled anywhere else, and they have produced a fair-to-good yield of commercially acceptable tubers. Their resistance has been similar to that of *S. demissum*, although not as complete. These selections have reacted similarly to all races of fungus to which they are susceptible. Although the level of field resistance has varied with individual clones, it is encouraging to note that the resistance shown by the selections made 4 years ago has been maintained in subsequent field tests (FIGURE 4). This fact provides some hope that this field resistance has some degree of stability.

All degrees of field resistance have been found in the selections made at Toluca. The resistance is inherited, and it tends to prevail in certain families. Certain parents give a much higher proportion of field-resistant progeny than others. Very little is known of the genetics of this field resistance; it appears, however, that many genes are involved. At the present time the most reliable method for measuring this resistance is by the field test at Toluca. Eventually, it is hoped that greenhouse techniques can be developed for making selections with field resistance, thus avoiding the planting of large numbers of susceptible clones in the field.

It is possible, of course, that there may yet appear new races that will blight the field-resistant selections more severely. However, it can be pointed out that *S. demissum* has maintained its very high level of field resistance after annual exposure to the pathogen for many hundreds of years. Furthermore, even the low-level resistance of such varieties as Alpha and Sebago has persisted for many years. These facts lend some support to the hope that the field resistance found in some of these selections will not be as deceptive as the strictly racial type of resistance.

In Mexico there occur other wild species of *Solanum* that are fully as resistant as *S. demissum* but which, so far, have been neglected in potato improvement programs. Doubling (with colchicine) the chromosome number of the normally diploid species *S. bulbocastanum* resulted in a tetraploid clone that has been crossed with *S. tuberosum*. Both *S. bulbo-*

FIGURE 4. Resistant selections in 1956 field-resistance test at Toluca. (A) Selections made in 1953 are in 11-row blocks 50 ft. long, on either side of the susceptible check row, Bintje, indicated by arrow. Photographed July 12, 1956. (B) Two weeks later the Bintje check row is dead. Resistant selections are still thriving. Photographed July 27, 1956.

castanum and the highly resistant *S. pinnatisectum* are being recognized as useful sources of blight resistance. It is entirely possible that blight resistance derived from interspecific crosses between resistant *Solanum* species will be even more stable and complete than that of any one species. There are many problems to be solved before such "hybrid resistance" can be incorporated in a commercial potato variety, but a start has been made. The use of new sources of resistance is important because, the broader the germ plasm basis from which we draw resistance, the greater the chance for ultimate success.

The brief and preliminary success we have had in Mexico can be the basis for no more than a cautious optimism. However, it is reassuring to know that the fight has now been carried to the pathogen in its own home. If it can be dominated there, victory over this century-old plant disease may not be distant.

Acknowledgments

The author expresses his deep appreciation to Javier Cervantes, Leopoldo Servín, and Jorge Galindo, of the Oficina de Estudios Especiales, Secretaría de Agricultura y Ganadería, Mexico, D. F., Mexico, for their devoted and expert assistance in the research work reported in this paper.

References

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2. BLACK, W., C. MASTENBROEK, W. R. MILLS & L. C. PETERSON. 1953. A proposal for an international nomenclature of races of *Phytophthora infestans* and of genes controlling immunity in *Solanum demissum* derivatives. Euphytica. **2**: 173-178.
3. REDDICK, D. 1943. Development of blight immune varieties. Am. Potato J. **20**: 118-126.
4. NIEDERHAUSER, J. S., J. CERVANTES & L. SERVÍN. 1954. Late blight in Mexico and its implications. Phytopathology. **44**: 406-408.

CONFERENCES HELD

SECTION OF PHYSICS AND CHEMISTRY

MAN-MADE FIBER PROGRESS

Friday, October 12, 1956

Conference Chairman: J. J. Press
Polytechnic Institute of Brooklyn and
U.S.N. Clothing Supply Office, Brooklyn, N. Y.

A REVIEW OF NEW FIBER DEVELOPMENTS

Session Chairman: J. J. Press
Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

9:00 A.M.

Greetings from the Academy – Frank C. Collins, Chairman, Section of Physics and Chemistry, The New York Academy of Sciences, New York, N. Y., and Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

"Cellulose and Cellulose Acetate Fibers" – John A. Howsmon, American Viscose Corporation, Marcus Hook, Pa.

"Polyamide and Polyester Fibers" – W. W. Heckert, E. I. du Pont de Nemours and Company, Wilmington, Del.

"Acrylic and Other Vinyl Fibers" – Frank J. Soday, The Chemstrand Corporation, Decatur, Ala.

ADVANCES IN FIBER APPLICATION

Session Chairman: J. H. Dillon
Textile Research Institute, Princeton, N. J.

2:00 P.M.

"Moisture, Temperature and Fiber Performance" – J. J. Press, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

"Problems and Advances in the Dyeing and Finishing of Man-Made Fibers and Fabrics" – P. L. Meunier, E. I. du Pont de Nemours and Company, Wilmington, Del.

"New Horizons with Stretch and Bulk Yarns" – Martin H. Gurley, Charlotte, N. C.

"What the Textile Consumer Expects from Science" – Jules Labarthe, Mellon Institute of Industrial Research, Pittsburgh, Pa.

SECTION OF BIOLOGY
and
SECTION OF PSYCHOLOGY

MEPROBAMATE AND OTHER AGENTS USED IN MENTAL DISTURBANCES

Thursday, October 18 and
Friday, October 19, 1956

Conference Co-Chairmen
James G. Miller, Mental Health Research Institute,
University of Michigan, Ann Arbor, Mich.
Frank M. Berger, Medical Director,
Wallace Laboratories, New Brunswick, N. J.

CHEMISTRY, PHARMACOLOGY AND MODE OF ACTION OF MEPROBAMATE

Session Chairman: Harry Beckman
Marquette University School of Medicine, Milwaukee, Wis.

9:00 A.M. –
Greetings from the Academy – Hilary Koprowski, Chairman, Section of Biology, The New York Academy of Sciences, New York, N. Y.; Lederle Laboratories Division, American Cyanamid Company, Pearl River, New York.

"Chemistry and Mode of Action of Tranquilizing Drugs" – Frank M. Berger, Wallace Laboratories, New Brunswick, N. J.

"Experimental Studies of Behavioral Effects of Meprobamate on Normal Subjects" – Donald G. Marquis, Ralph W. Gerard, E. Lowell Kelly, James G. Miller, and Anatol Rapport, University of Michigan, Ann Arbor, Mich.

"Some Effects of Meprobamate and Other Drugs on Conditioned Fear and Emotional Behavior" – Howard F. Hunt, University of Chicago, Chicago, Ill.

"Effects of Meprobamate on Imprinting in Water Fowl" – Eckhard H. Hess, University of Chicago, Chicago, Ill.

"Effect of Tranquilizers on Conditioned Reflexes" – Carl E. Pfeiffer, Emory University, Atlanta, Ga.

THE TREATMENT OF PSYCHONEUROTIC CONDITIONS

Session Chairman: Edwin F. Gildea
Washington University, School of Medicine, St. Louis, Mo.

2:00 P.M. –

"The Effects of 'Ward Tension' on the Quality and Quantity of 'Tranquilizer' Utilization" – Melvin Sabshin and Sydney B. Eisen, Institute of Psychosomatic and Psychiatric Research and Training, Michael Reese Hospital, Chicago, Ill.

"The Comparative Effects of Tranquilizers in Hospitalized Psychoneurotics" – Leo Alexander, Boston State Hospital, Boston, Mass.

"Treatment of Anxiety States with Meprobamate" – Walter A. Osinski, Albany Hospital, Albany, N. Y.

"The Use of Meprobamate and Other Tranquilizers in Air Force Personnel" – Noah M. Dixon, Medical Services, 138th U.S.A.F., Hospital, Orlando Air Force Base, Orlando, Fla.

"Electromyographic Studies with Meprobamate and Other Drugs in Anxious Patients" – Herman A. Dickel, Portland, Ore.

THE TREATMENT OF PSYCHIATRIC AND OTHER CONDITIONS WITH MEPROBAMATE

Session Chairman: Harry C. Solomon
Harvard Medical School and Boston Psychopathic Hospital,
Boston, Mass.

9:00 A.M. –

"Use of Meprobamate in Chronic Psychiatric Conditions" – Leo Hollister, Medical Service, Veterans Administration Hospital, Palo Alto, Calif.

"Meprobamate in Senile Psychoses" – Willis H. Bower, McLean Hospital, Waverly, Mass.

"The Use of Meprobamate Postoperatively" – Timothy A. Lamphier, Boston, Mass.

"Study of Meprobamate in Alcoholism" – Leon A. Greenberg, Yale University, New Haven, Conn.

"Study of Meprobamate in Patients with Headache" – Arnold P. Friedman, Montefiore Hospital, New York, N. Y.

"Clinical Evaluation of Meprobamate in Prepsychotic and Disturbed Children" – Harry R. Litchfield, Brooklyn Women's Hospital and East New York Dispensary, Brooklyn, N. Y.

USE OF MEPROBAMATE IN MUSCLE SPASM

Session Chairman: H. Houston Merritt
Columbia University, College of Physicians and Surgeons,
New York, N. Y.

2:00 P.M. –

"The Value of Muscle Relaxants in Disorders of Muscle Tone" – Edward B. Schlesinger, Neurological Institute, Columbia University, New York, N. Y.

"Use of Meprobamate and Other Muscle Relaxants in Muscle Spasm Due to Rheumatic Conditions" – Richard T. Smith, Benjamin Franklin Institute, Philadelphia, Pa.

"Use of Meprobamate in the Treatment of Skeletal Muscle Spasm" Julius S. Neviaser and S. H. Eisenberg, Emergency Hospital, Washington, D. C.

"Use of Meprobamate in Cerebral Palsied Patients" – Harriette Gilette, Atlanta, Ga.

"The Effect of Meprobamate on the Basal Ganglia in Children" – Henry W. Baird, III, E. G. Szekely, E. A. Spiegel and H. T. Wycis, St. Christopher's Hospital for Children, Philadelphia, Pa.

NEW MEMBERS

Elected June 21, 1956

SUSTAINING MEMBERSHIP

Binns, Silas O., M.D., Medicine. Urologist, Private Practice, Newport News, Va.
Jaworski, Hannibal L., M.D., Biology. Staff, Hillcrest Hospital, Waco, Texas.
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Prats, Julio E. Rivera, M.D., Biology. Private Practice, San Sebastián, Puerto Rico.
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Waine, Hans, M.D., Internal Medicine. Assistant Clinical Professor, Tufts University Medical School, Boston, Mass.
Wolford, John Leland, M.D., Cardiology. Private Practice, Louisville, Ky.

ACTIVE MEMBERSHIP

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Elected July 13, 1956

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Elected August 15, 1956

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McConnell, John E.W., Ph.D., Food Processing. Process Engineer, National Canners Association, Berkely, Calif.

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